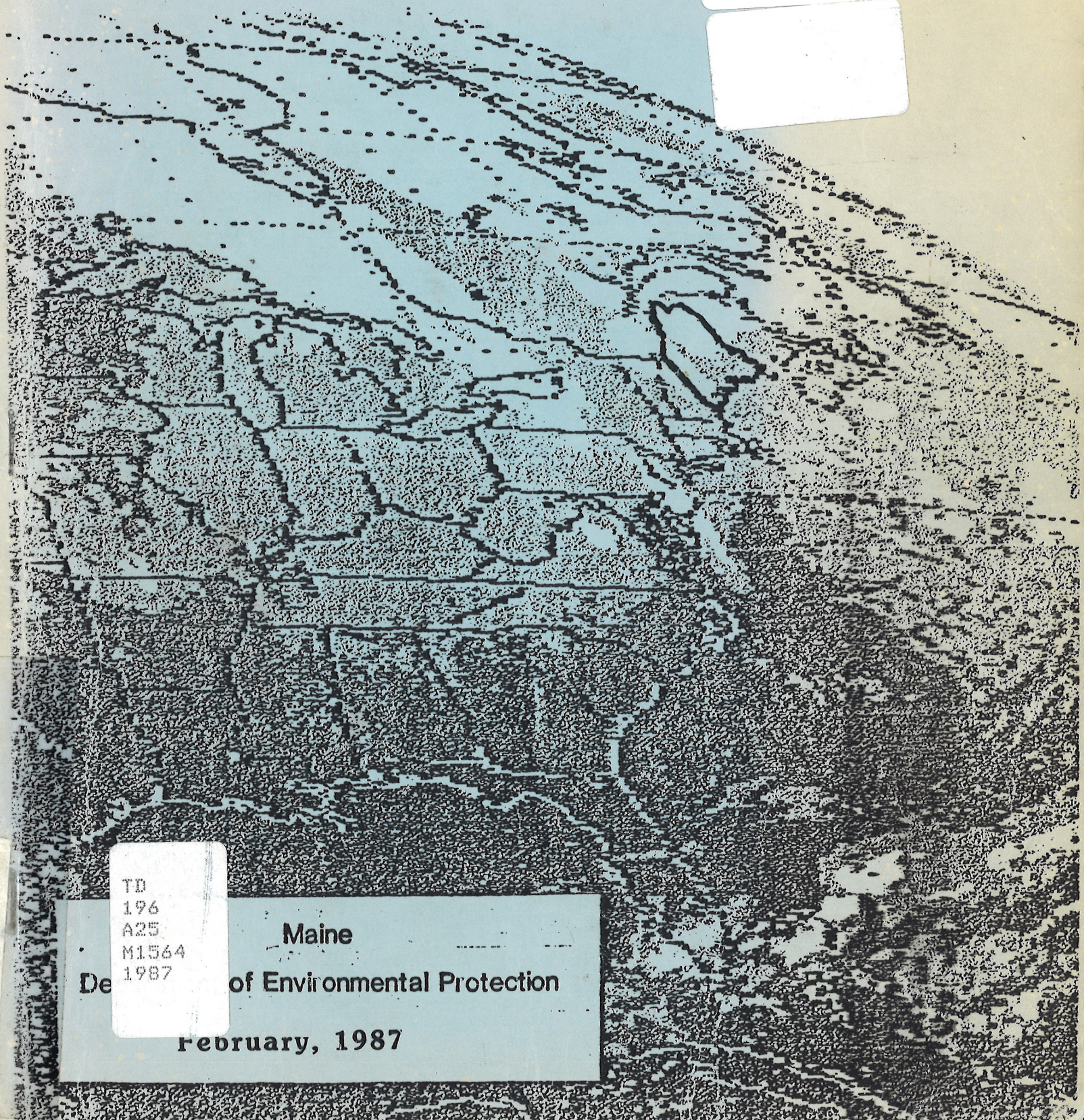
2-1987

Maine Acid Rain Study : Reports

Maine Department of Environmental Protection

MAINE ACID RAIN STUDY

Reports



Maine

De[illegible] of Environmental Protection

February, 1987

ACID RAIN PRECURSOR INVENTORY

AND EVALUATION

TABLE OF CONTENTS

STATE OF MAINE
NITROGEN OXIDES AND SULFUR DIOXIDE
ACID RAIN PRECURSOR INVENTORY AND EVALUATION
REPORT TO THE LEGISLATURE

BACKGROUND

State Inventory

In the first regular session of the 112th Legislature in 1985, H.P.263-L.D.317, "An Act to Control Acid Rain" was adopted. As part of the requirements of this legislation, the Department of Environmental Protection (DEP) was required to prepare a current and potential inventory of nitrogen oxide emission sources in the State of Maine. Also, an evaluation of the contribution of nitrogen oxides to acid deposition and other air pollution problems in the State was to be made. The inventory and evaluation were scheduled for completion by January 31, 1987.

NAPAP 1985 Emissions Inventory

The "Acid Precipitation Act of 1980" (Title VII of P.L.96-294) established a long-term federal inter agency program to coordinate and expand research on problems posed by acid deposition This program was called the National Acid Precipitation Assessment Program (NAPAP). Among the priority objectives of NAPAP was the development of a nationwide emissions inventory of sources of acid rain precursors that may contribute to the formation of acid precipitation.

NAPAP is composed of eight task groups, each having specific technical responsibilities. The Task Group on Emissions and Controls is responsible for providing an inventory of emissions for the 1985 calendar year from sources thought to be important in acid deposition processes to other NAPAP Task groups and to Federal and State Government Agencies.

The United States Environmental Protection Agency (EPA) has the principal responsibility for developing the point and area source emission estimates upon which the emissions inventory will be based and for developing the 1985 emissions inventory. EPA is coordinating the efforts of the State air pollution control agencies who are collecting and analyzing the 1985 emissions inventory data. The projected date for completion and release of the 1985 NAPAP Emissions Inventory (Version I) to users is January 1988.

The National Emission Data System (NEDS) was established in late 1971. Its primary purpose is to provide a centralized source/emissions data bank using a mainframe computer system. The NEDS system is being employed for the 1985 NAPAP Emissions Inventory. The individual State air pollution control agencies will have the primary role in the inventory development by obtaining and supplying new 1985 NEDS data. These data are to be sent to each State's respective EPA Regional Office and from there they are sent to the EPA Office of Air Quality Planning and Standards (OAQPS) in Washington.

Each State was required to contact each major source to obtain detailed emissions and facilities data for each point within that source. This data was used to calculate and confirm plant emissions totals and for encoding the NEDS data and checking the forms for errors. EPA estimates that, after the data have been processed while undergoing quality assurance review, a draft report of the U.S. Point source emissions inventory will be completed by June, 1987. A corresponding report for area source emissions estimates will be completed by August, 1987. EPA also expects to have new computer models operational in 1987 or 1988 that will incorporate non-linear processes and up-to-date atmospheric chemistry and this most comprehensive emissions inventory can be employed in making acid deposition estimates with a higher level of confidence.

INTRODUCTION

There are two principal acid rain precursors that are produced in substantial quantities in the State of Maine. These are NO_x and SO_2. NO_x stands for Nitrogen Oxides, which are mainly comprised of NO and NO2. SO_2 stands for Sulfur Dioxide. Both NO_x and SO_2 are produced by combustion processes such as coal or oil fired electric utility plants, oil fired industrial boilers and process heaters, automobiles, and even residential space heating stoves and furnaces.

SO_2 and NO_x are oxidized after they are emitted from their sources to form sulfates and nitrates which are eventually deposited as sulfate and nitrate aerosols and particulates or even as sulfuric acid or nitric acid, respectively. Volatile organic compound (VOCs) are released into the atmosphere by incomplete combustion by fuel burning sources or by the evaporation of liquid solvents or gasoline. These VOCs are precursors of ozone which can interact photochemically with the acid rain precursors SO_2 and NO_x and can influence the transformation into the respective acids.[1] The resultant complex mixture of aerosols,dissolved gases, and particulate matter undergo photochemical reactions while being transported by the weather systems and are eventually incorporated into the precipitation that falls to the earth downwind from the fuel burning sources. Some of these aerosols, gases and particulate matter are deposited at the earth's surface as "dry deposition" by impaction and absorption (See Appendix B : Atmospheric deposition processes).

Predictions have been made for the long term averages of sulfur deposition in the Northeastern United States, using a linear computer model, and the following generalizations were made: approximately 25% of the SO_2 emissions from sources in the Northeast reach the earth as wet deposition, i.e. rain, snow or fog; a nearly equal amount, about 30%, are collected on earth surfaces in the form of particulates or absorbed gases; the remaining 45% is assumed to be carried out over the Atlantic with an unknown fate.

Since acid droplets, sulfate and nitrate particles and aerosols may form and fall a few miles away from the fuel burning sources or travel hundreds of miles with the weather systems in which they are formed, these pollutants can affect the environment adversely at even large distances from their sources. Computer modeling studies have estimated for long term averages in the eastern United States, that up to 1/3 of the acidic deposition can come from sources within 120 miles away. Another 1/3 is suggested to come from sources between 120 and 300 miles away and the remaining 1/3 from sources over 300 miles away.

[1] Appendix A for a summary of the chemical reactions involving NO_x, Ozone and Ozone precursors).

The largest concentration of power plants and boilers burning high-sulfur coal and that produce the highest concentration of SO_2 emissions are those that are located in the Ohio River basin. It has been calculated that as much as 50% of the total U.S. Sulfur emissions come from 8 states in that area:Ohio, Indiana, Pennsylvania, Illinois, Missouri, Kentucky, West Virginia, and Tennessee. Approximately two-thirds of the total SO_2 emissions in the Eastern United States are produced by coal fired electric utility plants. The principal sources of NO_x on the other hand are automobiles (although power plants and industrial boilers produce significant amounts as well.)

It has been observed that the total emissions of SO_2 increased since the late nineteenth century and a maximum was reached in the early 1970's. Since that time, the SO_2 emissions have decreased in the Northeast by about 25%. The emissions of NO_x have exhibited a different behavior by beginning with a sharp, steady increase in the 1940's and, after reaching a maximum in the late 1970's, have now decreased by about 5% from that maximum. The emissions reductions observed in the Northeast are the direct result of the institution of emission controls on automobiles (NO_x reductions) and on power plants and industrial boilers (SO_2 reductions).

EMISSIONS INVENTORY

General

An air pollutant emissions inventory is a systematic tabulation of air emission sources and the magnitude of their emissions for a certain geographical area or areas. The inventory should provide information in such a way that planning agencies and legislative bodies can take the technical data presented in them and be able to utilize the information they contain in the decision making process. Sources should be divided into categories and subcategories that have the greatest significance for the planning or regulatory agencies using them. The State of Maine DEP has attempted to prepare the emissions inventory in various formats in order to make them useable by a large cross-section of users. The various formats described in the sections below are presently available to prospective users or are in various stages of completion.

Acid Rain Precursors Inventory

General

As mentioned above, the DEP is involved in the NAPAP 1985 Emissions Inventory . Data which had been obtained from detailed questionnaires sent to major point sources were encoded in NEDS format and included in the Emission Inventory System(EIS) that is used by the State of Maine, Bureau of Air Quality Control. These data for the major point sources (1000 tons/year or greater) were available in the Fall of 1986 for the calendar year 1985. An EIS Quick Look Report was created and down loaded from the minicomputer to the microcomputer as a database file and then subdivided as a set of spreadsheets with one for each county of the State. New spreadsheet columns were created to provide actual and potential emissions calculations. These spreadsheets are the core of the point source emissions inventory described below.

The DEP is currently verifying the data for the major point sources and is in the process of obtaining 1985 calendar year data for the smaller point sources and area sources. For emission inventories and summaries described below, data for the smaller sources were obtained from the most recent information in the license files of these sources, such as air emission license renewal applications and fuel use data from earlier years (which is often a good approximation for the annual fuel usage for any year). Mobile source emissions were obtained from estimates of vehicle miles traveled (VMT) provided by the State Department of Transportation (DOT) and calculated emission factors using a computer model called Mobile 3 (See the next section for more detail on the procedures used).

Each of the inventories presented below have been developed as a spreadsheet on a microcomputer (using FrameworkII, by Ashton-Tate) and are or will be available as a spreadsheet file on magnetic media (5 1/4 inch floppy diskette) or as hard-copy printout on paper. The spreadsheet format is useful since it has been designed so that the emissions for each source can be automatically recalculated when the fuel process rate, sulfur content or some other factor is updated. Not only are the annual emission rates of the individual sources recalculated but also the subtotals and totals of all the sources are recalculated.

Summary Form

The Summary Form Inventory , presented in Table I, was obtained using information from various sources. Its format is one of the simplest of those currently available. The compilation of sources is divided into two broad categories: Stationary Sources and Mobile Sources. No distinction is made between point and area sources since the categories chosen do not require that designation nor does it make the information tabulated any more useful. Stationary sources are subdivided into fuel combustion sources, waste burning sources and industrial process sources. The fuel combustion sources are further subdivided into (1) utilities, (2) industrial, (3) commercial, and (4) residential sources. The first two of these fuel combustion categories contain data obtained from the more comprehensive point source inventory described below. For the second two categories, commercial and residential fuel burning sources, the emissions were estimated using fuel combustion data that were obtained from the "Comprehensive Energy Resources Plan. September 1985" prepared by the State of Maine Office of Energy Resources (OER). It should be noted that 1985 fuel combustion data were not available from the OER at this time so data for calendar year 1984 were employed with a small extrapolation as an estimate for 1985 fuel usage. The estimated emissions for utilities and industrial sources obtained from the detailed point source emissions inventory compares remarkably well with the values estimated using the OER fuel combustion figures. (See Appendix C: OER Fuel Consumption Data, NO_x and SO_2 Emissions.Estimates. These are emission estimates for three broad categories: a combined utilities/industrial source category,commercial sources, and residential sources for seven fuel types.)

TABLE I

1985
STATE OF MAINE
ACID RAIN PRECURSOR EMISSIONS INVENTORY

	NOX EMISSIONS (TONS/YEAR)	SO2 EMISSIONS (TONS/YEAR)
STATIONARY SOURCES		
FUEL COMBUSTION		
UTILITIES	2,574	12,875
INDUSTRIAL	17,399	41,711
COMMERCIAL	5,232	23,293
RESIDENTIAL	3,273	4,877
TOTAL FUEL COMBUSTION	28478	82,756
WASTE BURNING		
AGRICULTURAL DEBRIS	240	60
FOREST MANAGEMENT	20	5
INCINERATION	250	35
DUMPS	79	13
TOTAL WASTE BURNING	589	113
INDUSTRIAL PROCESSES		
CHEMICAL		1,336
WOOD & PAPER	1,341	3,693
OTHER		
TOTAL INDUSTRIAL PROCESSES	1,341	5,029
TOTAL STATIONARY SOURCES	30,408	87,898
MOBILE SOURCES		
ON-ROAD VEHICLES		
LIGHT-DUTY PASSENGER	16,613	
LIGHT & MEDIUM DUTY TRUCKS	9,058	
HEAVY-DUTY GAS TRUCKS	2,559	
HEAVY-DUTY DIESEL TRUCKS	12,308	
MOTORCYCLES	81	
TOTAL ON-ROAD VEHICLES	40,619	
OTHER MOBILE		
OFF-ROAD VEHICLES AND EQUIPMENT		
LAWN AND GARDEN EQUIPMENT	64	NEG.
MOTORCYCLES AND ATVS	5	NEG.
FARM EQUIPMENT	761	36
INDUSTRIAL EQUIPMENT	190	12
CONSTRUCTION EQUIPMENT	488	34
TRAINS		
MARINE	156	21
AIRCRAFT		
TOTAL OTHER MOBILE	1,664	103
TOTAL MOBILE SOURCES	42,283	103
TOTAL ALL SOURCES	72,691	88,001

The estimates made for three of the Waste Burning categories, (1) agricultural debris, (2) forest management, and(4) dumps used procedures outlined in the report entitled "Hazardous Air Pollutants (HAPS) In Maine: Emissions Inventory and Ranking System" prepared by the DEP Bureau of Air Quality Control and the DHW Bureau of Health in March, 1985. The third category - incineration - presently contributes a fairly small amount of NO_x and SO_2 (250 tons/year of NO_x and 35 tons/year of SO_2) but that will dramatically change once the new resource recovery incinerators go online in the near future. For example,consider the following resource recovery systems (incinerators) :(1) Maine Energy Recovery Company (MERC) - Anticipated startup date for this Biddeford area resource recovery system is 1987 with the potential of 625 tons/year of NO_x and 88 tons/year of SO_2. (2) Regional Waste Systems (RWS) - This Portland based resource recovery system has an anticipated startup date of 1988-1989 with a potential of about 250 tons/year of NO_x and 67 tons/year of SO_2. (3) Penobscot Energy Recovery Company (PERC) -Bangor area system, with a startup date of 1988-1989 and with a potential of 688 tons/year of NO_x and 97 tons/year of SO_2. The NO_x emissions for the incineration category will increase by about 1563 tons/year and the SO_2 emissions will increase by 252 tons/year once these new incinerators are operational. Other resource recovery systems are also being contemplated for Augusta and possibly Brunswick and these could contribute substantially to the emissions of both NO_x and SO_2. The estimated emissions of the three new resource recovery systems described above represent about 5% of the total NO_x emissions from stationary sources or about 2% of the combined total of mobile and stationary sources.

Under the category of industrial processes, the two major categories are the Chemical and the Wood and Paper categories. In the Wood and Paper category, only those processes that are specific to the pulp and paper industry have been included. These processes are specifically the recovery boiler process of burning black liquor solids, lime kilns, smelt dissolving tanks, etc. and other components associated with the digesting of wood pulp. The emission factors for kraft pulp mills are usually given in units of pounds of NO_x or SO_2 per air dried ton of unbleached pulp. The information supplied on the emissions inventory questionnaire for these major sources of pollutants for the fuel process rate of the recovery boiler was usually expressed as tons of black liquor solids BLS (red liquor solids for sulfite pulping). These numbers had to be converted to air dried tons of pulp by using the conversion factor specific for each mill for the year in question (1985) and these were obtained for each mill.

Mobile source emissions for on-road vehicles have been calculated for the entire State of Maine using a set of scenarios that take into account the differences of seasons of the year, the differences of annual average temperatures of the different regions of the State, and the different types of roads throughout the State. (See Appendix D for scenarios used in MOBILE3 model calculations). The composite emission factor obtained from the MOBILE3 model is multiplied by the Vehicle Miles Traveled (VMT) for the year in question (1985) for the entire State. To obtain the mobile source emissions for each county, the total emissions are proportioned according to county population with the underlying assumption being that VMT, vehicle type, number and types of roads can be averaged over the entire state (on a population basis). While this type of an assumption is not perfect, it provides a reasonable first approximation for the types of area source emissions that are produced by mobile sources. (See Appendix E for on-road mobile source emissions estimates by county).

For off-road vehicles and equipment under the general category of other mobile sources, the method used to make emission calculations is described in detail in the report entitled "1979 Maine Area Source Inventory" prepared in 1981 by the DEP Bureau of Air Quality Control. An estimated distribution of lawn and garden equipment, etc. was employed along with the total statewide use of gasoline and diesel fuel for off-highway mobile sources. These values can then be apportioned according to county population as was the highway mobile sources.

Point Source Inventory

As mentioned above, a detailed point source inventory for all major and smaller stationary sources that consists of a microcomputer spreadsheet for each county of the State was obtained from a subset of data contained in the Emissions Inventory System (EIS) that is currently being updated by the Bureau. The major point sources (generally those sources generating 1000 or more tons of pollutants) have been updated in this database and all now have the most current fuel process rate data available (for calendar year 1985). The new data included were obtained on questionnaires sent out by the Bureau of Air Quality Control and these data are currently being verified. The smaller point sources (less than 1000 tons per year) in most instances did not receive questionnaires in the first batch that were sent out but more questionnaires will be sent out in the near future. Some of the fuel usage figures included in this data base extended back to 1979 for smaller sources. To make the emissions calculations more indicative of current fuel usage, the license files were consulted for these smaller licensed sources and more recent fuel usage figures were obtained from license application forms, modeling reports, etc. In many instances data not any more current than that for 1984 could be obtained and sometimes it was even older than that. Frequently the variation in fuel usage was minor from year to year and therefore earlier data provided a reasonable basis for estimating emissions for the year 1985.

Each county spreadsheet has the individual emission source listed in a column and the corresponding heat input capacity (in millions of BTU/hr) for each fuel burning source. The fuel process rate, which is expressed in thousands of gallons of fuel per year (except when solid fuels are used and these are expressed in tons per year, etc.), and the sulfur content are also tabulated for each source and serve as the basis for the emissions calculations for the various pollutants. The actual and potential emissions for each source are calculated automatically in the appropriate spreadsheet cells whenever the fuel process rate or fuel sulfur content are changed or updated. The potential emissions are keyed to the design input capacity of each of the emission sources. A subtotal for each county is also included in each spreadsheet. A summary of these county totalsis given in Table II on page 9.

The data presented in this point source inventory do not include new sources that will be coming on-line in the next few years such as the 10 megawatt wood-fired electric generating plant in Greenville (Swift River), the 17 megawatt plant in Chester (AEDI Chester), the 15 megawatt unit in Athens (Gorbell/Thermo Electron) and the 672 million BTU per hour unit in Stratton (ARS Group, Inc.), etc. These new sources have the potential to increase the NO_x emissions by more than 10% of the total NO_x emissions from the Stationary sources or more than 4% of the Total NO_x emissions for the State of Maine. For comparison, the total NO_x emissions for all the residential space heating in the State of Maine is the approximately the same percentage as that estimated for these new sources described above.

TABLE II

STATE OF MAINE

FUEL COMBUSTION CATEGORY
UTILITIES AND INDUSTRIAL SOURCES
1985 NOX EMISSIONS
SUMMARY BY COUNTY

	NOX EMISSIONS (TON/YEAR)	
COUNTY	ACTUAL	POTENTIAL
ANDROSCOGGIN	380	921
AROOSTOOK	640	2496
CUMBERLAND	4239	11661
FRANKLIN	1966	2769
HANCOCK	696	3370
KENNEBEC	845	1811
KNOX	1729	1399
LICOLN	379	1333
OXFORD	1551	1578
PENOBSCOT	4263	6154
PISCATAQUIS	50	96
SOMERSET	1178	2467
WALDO	81	299
WASHINGTON	776	1138
YORK	427	1004
	19200	38496

In Appendices F and G , the 1985 NO_x emissions data for the State of Maine are presented in graphical form, both as a bar graph and a pie chart. It is readily apparent from both types of representations that the major source of NO_x emissions for the State of Maine is the Mobile sector. Mobile sources contribute about 58% of the total NO_x emissions in the State of Maine and the next largest category is industrial sources with about 24% of the total. Utilities and residential sources both contribute about 4% while commercial sources contribute about 7% of the total NO_x emissions in the State.

In a similar set of graphs in Appendices H and I , SO_2 emissions data are presented. In these graphs, the approximately 47.5% of the total SO_2 emissions are seen to come from the industrial source category. Both commercial and utility sources fall closely behind with 26.5% and 14.6%, respectively. Mobile sources contribute an almost negligible amount of SO_2 while residential and the two remaining sources each contribute about 6% of the total.

Ozone Point Source Inventory

In order to provide the necessary emissions information for an ozone modeling study, emission inventories for the years 1980 through 1984 were obtained for the six southern most counties of the State of Maine. In addition to providing Volatile Organic Compound (VOC) emissions estimates, this inventory also provides calculations of SO_2 and NO_x emissions. The inventory placed more emphasis on obtaining estimates of reactive hydrocarbons emissions since it is the major precursor of Ozone. The location of each emission source is described both in terms of its UTM coordinates or the Latitude and Longitude. A similar series of inventories for the same time periods is contemplated for the northern counties of the State in the upcoming months. These inventories are also in a spreadsheet format similar to the others described aboveand will be available to interested parties in the near future.

ACID RAIN MONITORING

National Atmospheric Deposition Program

The National Atmospheric Deposition Program (NADP) is a cooperative research program that was organized in 1978 by the North Central Region of the State Agricultural Experiment Stations. In 1982, the program was endorsed by all four regions of the State Agricultural Experiment Stations and is now referred to as the Interregional Research Project (IR-7). It was determined that it was essential that long term trends in the composition and concentration of acid rain be established and that measurements be carried out for a period of 10 years or more.

In response to these needs, the NADP network of acid rain monitoring stations was established and it first began operations in July of 1978 with 7 stations. The earliest site in the State of Maine was the Greenville Station which began operating in November, 1979. In 1982, the United States Congress created the National Acid Precipitation Assessment Program (NAPAP) in order to provide increased support for research into the causes and effects of acid deposition. During that period of time, the NADP program became a truly cooperative venture with the participation of the Federal Interagency Task Force on Acid Precipitation, State Agencies, and private research organizations. In 1982, the NADP was asked to assume responsibility for coordinating the operation of the National Trends Network of NAPAP. The combined NADP/NTN acid rain monitoring sites have reached a total of 192 operating stations as of November, 1986 and the total should reach almost 200 by early in 1987.

A specially designed automated wet/dry sampler is used to capture precipitation at the nearly 200 NADP/NTN monitoring sites across the U.S. Each of these sites also has a rain gage with which to record the weekly precipitation. Only the wet deposition portion is currently being collected since problems in measuring the dry component have not as yet been resolved. At the present time, there are five acid rain monitoring stations that are being operated in the State of Maine:

(1) Greenville station - established in November, 1979.

(2) Caribou station - established in April, 1980.

(3) Bridgton station - established in September, 1980.

(4) Acadia National Park (McFarland Hill site) - established in November, 1981.

(NOTE: Prior to this, another site called the Paradise Hill site was operated between November 18, 1980 and November 3, 1981.)

(5) Presque Isle - established in June, 1984.

The samples that are collected each week are sent to the Central Analytical Laboratory (CAL) located at the Illinois State Water Survey Laboratory in Illinois. At this laboratory, the samples are analyzed for pH, conductivity, sulfate ion $[SO4]^{--}$,nitrate ion $[NO3]^{-}$, ammonium ion $[NH4]^{+}$, sodium ion $[Na]^{+}$,chloride ion $[Cl]^{-}$, potassium ion $[K]^{+}$, calcium ion $[Ca]^{++}$, magnesium ion $[Mg]^{++}$, and hydrogen ion $[H]^{+}$. Before the rain samples are sent to the CAL laboratory, the site operator determines the amount of precipitation in grams by weighing the collection bucket. He or she also reads the strip chart from the nearby rain gage in order to record the amount of precipitation in inches and also measures the field pH of the sample as well as the conductivity.

Precipitation Monitoring in the State of Maine

Precipitation monitoring data for the the 5 Maine monitoring sites are summarized in Table III and Table IV. In these tables, data for the years 1980 through 1985 are summarized for the Acadia site and the Bridgton site while for the Greenville and Caribou sites the data are only summarized through 1984. Since the Presque Isle site has been operational for such a short time only a limited amount of data are available for it. The average precipitation weighted laboratory pH for Acadia and Bridgton for the period analyzed is 4.5. The remaining three sites' precipitation weighted average pH is 4.6.

Sulfate [SO4] and nitrate [NO3] deposition data is summarized in Table IV. Only the wet deposition portion is currently being measured since problems in measuring the dry component have not as yet been resolved. Corrections employing $[Na]^{+}$,$[Mg]^{++}$, and $[Cl]^{-}$ can be made to deposition values calculated to remove the contributions from non-anthropogenic sources, e.g. marine aerosols. The average sulfate deposition values range from 15 kilograms per hectare for Greenville and up to 19 kilograms per hectare for Acadia for the periods summarized in this table. The average nitrate deposition values range from 8 kilograms per hectare for Caribou and Greenville and up to 13 kilograms per hectare for Acadia. These are precipitation weighted averages for each year of

TABLE III

STATE OF MAINE
PRECIPITATION MONITORING

	PRECIPITATION WEIGHTED LAB pH				
YEAR	ACADIA	BRIDGTON	GREENVILLE	CARIBOU	PRESQUE ISLE
1980	4.55	4.72	4.40	4.49	-
1981	4.34	4.37	4.59	4.50	-
1982	4.49	4.38	4.54	4.67	-
1983	4.71	4.63	4.74	4.65	-
1984	4.59	4.49	4.61	4.60	4.60
1985	4.48	4.27	-	-	-

TABLE IV

STATE OF MAINE
NITRATE AND SULFATE DEPOSITION

YEAR	DEPOSITION (KILOGRAMS/HECTARE)									
	ACADIA		BRIDGTON		GREENVILLE		CARIBOU		PRESQUE ISLE	
	(NO_3)	(SO_4)*	(NO_3)	(SO_4)*	(NO_3)	(SO_4)*	(NO_3)	(SO_4)*	(NO_3)	(SO_4)*
1980	18	15	5	10	10	18	9	19	--	--
1981	14	24	12	22	9	17	9	22	--	--
1982	11	20	11	17	8	13	6	11	--	--
1983	10	18	8	16	8	14	7	15	--	--
1984	11	18	10	17	7	14	7	13	7	13
1985	12	19	9	14	--	--	--	--	--	--

*Corrected for Marine Aerosols

the summary period. The sulfate deposition values have been corrected for marine aerosols which are generally of no concern for sites that are situated 50 kilometers or more from the coast. When the sulfates are compared to nitrates (on a micro equivalents per liter basis) the ratio ranges from to 2.2 to 2.6 , indicating that sulfates comprise from about 68% to 72% of the total acid deposition for the monitoring stations in the State of Maine. This is identical to saying that nitrates contribute 28% to 32% of the total acid deposition in the State.

NO_x CONTRIBUTIONS TO ACID DEPOSITION AND OTHER POLLUTION PROBLEMS

Acid Deposition

In research that was sponsored by NAPAP, researchers from the Argonne National Laboratory [2] applied a linear computer model called the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model to source-receptor estimates of the contribution of nitrogen oxide emissions to nitrate deposition. In a paper published recently by these scientists, calculations were made showing estimated contributions to nitrate deposition in many states and provinces. Without specifying which receptor was chosen in the State of Maine, it was estimated that Maine sources contributed about 6% of the total nitrate deposited in the State. The largest contribution (30.6%) is predicted to come from the 8 Ohio Basin states described earlier. The other New England States plus New York and New Jersey were estimated to contribute 26% of the total nitrate deposited here. The Canadian Provinces were estimated to contribute another 21%, with Quebec and Ontario contributing almost 19% of that 21% (Quebec by itself was estimated to contribute 12.3% of Maine's nitrate deposition).The nitrate deposition when averaged over the entire State's area was calculated to be about 4 Kg/Hectare which is low compared to the actual values of 8 to 13 Kg/Hectare that is being measured in the State of Maine. The model is not intended to provide absolute values of nitrate deposition but it can be used to show relative contributions to deposition from various sources. As mentioned earlier, analysis of sulfate and nitrate concentrations in rain water have shown that nitrates contribute 28 to 32% of the total acid deposition in the State of Maine. (See Appendices J and K).

Ozone Pollution Problems

The various reaction mechanisms involved in the formation of Ozone(O_3) are described in Appendix A. Here one begins to appreciate the importance of VOC's and NO_x in the formation of ozone. These mechanisms can be used to explain the typical diurnal variations of NO_x and Ozone in urban atmospheres.

Nitric oxide (NO) concentrations are typically higher in the early morning since the organic radicals are not sufficiently plentiful to cause the conversion process from NO to NO_2 to proceed [Reaction 2]. As more radicals become available [Reaction 4], the NO to NO_2 conversion reaction rate increases and NO_2 becomes the dominant NO_x species. When the NO_2 to NO ratio becomes large enough, the Ozone concentration builds up [Reaction 5)]. The highest Ozone concentrations are usually observed many miles downwind from

[2] Prepublished data obtained from Jack Shannon and Barry Lesht, Environmental Research Division, Argonne National Laboratory, Argonne, Illinois.

their sources since the reactions involving organic gases are relatively slow. At the same time, the NO_2 concentrations can be decreasing as a result of the radical sink reaction [Reaction 6]. During the night in the air mass containing the pollutants, NO and O_3 combine to form NO_2 and O_2 [Reaction 3] until all available NO and O_3 molecules are used up, so the O_3 will approach a minimum at night.

The reactions summarized here are a few of the many that are possible but may be some of the more dominant reactions involving Ozone and NO_x. These interactions are quite complex and it is difficult to assess the impact of NO_x control strategies on ambient O_3 concentrations. For example:

(a) If NO_x emissions are held constant and volatile organic compound (VOC) emissions are diminished, fewer organic radicals [Reaction 4] are produced and the rate of O_3 formation slows down,

(b) If VOC emissions are held constant and NO_x emission are reduced, there is less competition by the NO_2 molecules [Reaction 5] for the same number of radicals, thereby speeding up the (O_3) production process.

The key to the effect of NO_x controls on the Ozone problem is whether the O_3 formation process is VOC limited or NO_x limited. If the VOC/NO_x ratio is less about 2 to 1, the amount of O_3 formed is limited by the availability of free radicals produced by the VOCs and therefore NO_x controls will have little effect. At higher ratios (greater than 5 to 1), the amount of O_3 formed is limited by the availability of NO_x. Thus, NO_x controls would tend to reduce the amount of O_3 produced.

Without detailed modeling studies of Ozone in the State of Maine where accurate NO_x and VOC emission inventories are employed, little can be predicted about the effects of NO_x controls on Ozone O_3 production now. At the very least, NO_x emission should not be allowed to increase and VOC emissions should be reduced as a first step to reduce Ozone emissions.

Visibility Problems

As mentioned earlier, NO_x pollutants consisting of NO and NO_2 interact photochemically to produce a complex mix of gases, aerosols, and particulates. Aerosol nitrate can cause "visibility impairment" and increased levels of total suspended particulate (TSP). Approximately 60% of aerosol nitrate is in the 0.1 to 2 micron size range. Particles in this size range are efficient light scatterers and therefore have a negative effect on visibility.

When one refers to "visibility impairment" this not only means "reduced visual range" but also "atmospheric discoloration". Anthropogenic "atmospheric discoloration" results almost exclusively from the absorption of light by gaseous nitrogen dioxide (NO_2) and soot particles containing elemental carbon. Nitrogen dioxide gas (NO_2) affects visibility by its property of absorbing light in the blue end of the spectrum. Around large urban centers of pollution, the light absorption by NO_2 may not appreciably reduce the "visual range" or the distance one may see clearly. However, a dirty-brown appearance is produced in the atmosphere by the presence of NO_2 gas. It also causes what is called "plume blight", the highly visible stack emissions caused by the release of NO_x gaseous pollutants into the atmosphere.

SUMMARY AND CONCLUSIONS

This report summarizes the efforts of the DEP Bureau of Air Quality Control with regard to preparing an air pollution emissions inventory with special emphasis on Nitrogen Oxides. An evaluation of the relative contribution of Nitrogen Oxides to the acid deposition being monitored in the State of Maine is also presented. Graphs have been prepared that readily show that mobile sources are the largest contributor to the total NO_x emissions in the State of Maine (about 58%). Industrial sources also are significant contributors to the total NO_x emissions (about 24% of the total). Utilities and residential sources both contribute about 4% of the NO_x emissions and commercial sources add 7% to the total NO_x emissions.

At the five NADP acid rain monitoring sites located in the State of Maine, data analyzed thus far have shown that nitrate (NO3) deposition values ranged from about 8 kilograms per hectare to about 13 kilograms per hectare. By comparison, sulfate (SO4) deposition values ranged from about 15 kilograms per hectare to 19 kilograms per hectare. When nitrate (NO3) values are compared to sulfate (SO4) on a micro equivalent per liter basis, one can conclude that the nitrates contribute 28 to 32% of the total acidic deposition collected as wet deposition.

The single largest emitting source category of acid rain precursors is the mobile source category with 42,283 tons per year of NO_x (58%). The second and third largest categories are the industrial source category and the commercial source categories with about 41,711 tons per year of SO_2 (47.5%) and 23293 tons/year of SO_2 (26.5%), respectively. The combined total of SO_2 and NO_x for these two sources are respectively, 59,100 tons/year and 28,525 tons/year. Electric generating plants (the utility category) add about 13,000 tons/year of SO^2 (17%)and about 3000 tons/year of NO_x (4%).

It has been suggested in a report prepared for the Northeast States for Coordinated Air Use Management (NESCAUM) and released in July 1986, that a variety of air emission control techniques can be employed to reduce the emissions of these acid rain precursors. A partial list of those techniques recommended includes switching to a lower sulfur fuel of the same type,switching to a different fuel (e.g. Natural gas were available), retrofitting with specially designed low NO_x burners, and employing boiler modifications to provide less excess air to the combustion zone. For mobile sources, suggested control measures include more stringent NO_x exhaust emission standards,inspection and maintenance (I/M) programs especially tailored for NO_x emission reductions, anti-tampering programs, and transportation control measures. Other possible methods suggested were to pay more attention to energy conservation and to employ non-fossil fuel sources such as wood and refuse for energy production as is already being done in several parts of the State.

APPENDIX A

Nitrogen Oxide Emission Mechanisms and Photochemical Reactions

When fuels such as residual oil, distillate oil, coal,etc. are burned in either external or internal (where possible)combustion sources, nitrogen oxides (NO_x) are formed. Part of the NO_x emissions result from the oxidation of elemental nitrogen and other nitrogenous compounds chemically bound in the fuels. The rest is produced as the thermal fixation (oxidation) of the free atmospheric nitrogen gas (N_2) normally found in the combustion air as it passes through the hot combustion zone of the combustion source. Nitric oxide (NO) is the chemical species principally formed in the hot combustion zone of industrial and utility boilers. The reaction can be expressed as follows:

$$N_2 + O_2 + [\text{ high temperatures }] \longrightarrow 2\ NO$$

where N_2 is either the elemental N_2 chemically bound in the fuel or the nitrogen gas found in the combustion air which is normal atmospheric air.

Generally, 90% of the total NO_x produced by combustion sources is nitric oxide (NO). This percentage changes as the exhaust travels up the chimney and reaction 1) takes place. Nitrogen dioxide (NO_2) makes up most of the remaining oxides of nitrogen. However, nitric oxides (NO) are converted to nitrogen dioxides (NO_2) by various mechanisms:

(1) $2\ NO + O_2 \longrightarrow 2NO_2$ (In high NO concentrations.)

(2) NO + Organic radicals $\longrightarrow$ Organic radicals + NO_2

(3) $NO + O_3 \longrightarrow NO_2 + O_2$ (In the presence of Ozone(O_3).)

(4) NO + VOC + [sunlight] $\longrightarrow$ NO_2 + Organic radicals (This is an example of a photochemical reaction that occurs in the presence of volatile organic compounds (VOC's) that are photochemically reactive.)

(5) $NO_2 + O_2 +$ [sunlight] $\longrightarrow$ $NO + O_3$ (This is the reverse of reaction (4) above in which NO_2 is produced but here the NO_2 is converted back to nitric oxide (NO) and Ozone (O_3).

(6) NO_2 + [Hydroxyl radical] $\longrightarrow$ HNO_3

Reaction (6) provides a sink for free radicals and shows one path by which nitric acid is produced. At night and on cloudy days, as long as Ozone is present, reaction (3) proceeds until the available Ozone is depleted. When there is sufficient sunlight, reactions (4) and (5) become dominant and the amount of NO_2 produced is a function of the amounts of NO and volatile organic compounds (VOCs) in the atmosphere and the amount of sunlight. The amount of NO_2 (and the amount of Ozone) in the ambient air therefore is a function of the daily variations in the photochemical processes which themselves are dependent on the amount of sunlight which varies seasonally and with the weather. These are just a few of the many possible chemical and photochemical reactions that are involved in the formation of nitrogen oxides and Ozone.

APPENDIX B

Atmospheric Deposition Processes

The following is a summary of the various pollutant removal mechanisms that play a role in acidic deposition. The mechanisms can be classified as either wet deposition or dry deposition.

Wet Deposition:

1) Rain out: Condensation on small particles that serve as nuclei for the formation of raindrops is a process that removes these particles from the air.

2) Droplet Growth: Gaseous and particulate pollutants are removed by dissolution and chemical changes of the pollutants during the growth phase of previously formed cloud droplets which eventually fall to the ground.

3) Washout: Pollutants are removed by pollutant scavenging below the clouds by the falling precipitation.

Dry Deposition:

1) Sedimentation: This is the dry removal of large particles by gravitational settling.

2) Accumulation: This removal process involves the coagulation and collision of small particles with large particles.

3) Impaction: This is the direct physical removal of small particles on ground surfaces, trees, leaves, buildings, etc. and other obstacles on impact.

4) Sorption: The removal of gaseous pollutants by adsorption and absortion on the various ground surfaces.

APPENDIX C

STATE OF MAINE
OFFICE OF ENERGY RESOURCES
FUEL CONSUMPTION DATA
NOX AND SO2 EMISSIONS ESTIMATES

UTILITIES/INDUSTRIAL SOURCES

FUEL TYPE	FUEL CONSUMPTION (UNITS/YEAR)*	NOX EMISSION FACTOR (LBS/UNIT)*	NOX EMISSION FACTOR (LBS/mmBTU)	NOX EMISSIONS (TONS/YEAR)	SO2** EMISSION FACTOR (LBS/UNIT)*	SO2** EMISSION FACTOR (LBS/mmBTU)	SO2 EMISSIONS (TONS/YEAR)
KEROSENE	1,386,000	.018	.129	12	.014	.101	10
DISTILLATE	8,064,000	.020	.133	81	.043	.284	172
RESIDUAL	327,348,000	.067	.479	10,966	.309	2.209	50,623
PROPANE	2,352,000	.013	.140	16	.000014	.00015	0
NATURAL GAS	775,000,000	.00020	.200	78	.0000006	.001	0
COAL	123,000	18.0	.667	1,107	38	1.400	2,325
WOOD	3,812,500	2.8	.156	5,338	.400	.022	763
TOTALS				17,597			53,892

COMMERCIAL SOURCES

FUEL TYPE	FUEL CONSUMPTION (UNITS/YEAR)*	NOX EMISSION FACTOR (LBS/UNIT)*	NOX EMISSION FACTOR (LBS/mmBTU)	NOX EMISSIONS (TONS/YEAR)	SO2*** EMISSION FACTOR (LBS/UNIT)*	SO2*** EMISSION FACTOR (LBS/mmBTU)	SO2 EMISSIONS (TONS/YEAR)
KEROSENE	2,730,000	.018	.129	25	.014	.101	19
DISTILLATE	81,228,000	.020	.133	812	.043	.284	1,730
RESIDUAL	122,220,000	.067	.479	4,094	.345	2.467	21,107
PROPANE	9,450,000	.009	.096	43	.000014	.00015	0
NATURAL GAS	1,123,000,000	.00010	.100	56	.0000006	.001	0
COAL	21,000	10.0	.370	105	38	1.400	397
WOOD	195,000	1.000	.056	98	.400	.022	39
TOTALS				5,232			23,293

RESIDENTIAL SOURCES

FUEL TYPE	FUEL CONSUMPTION (UNITS/YEAR)*	NOX EMISSION FACTOR (LBS/UNIT)*	NOX EMISSION FACTOR (LBS/mmBTU)	NOX EMISSIONS (TONS/YEAR)	SO2 EMISSION FACTOR (LBS/UNIT)*	SO2 EMISSION FACTOR (LBS/mmBTU)	SO2 EMISSIONS (TONS/YEAR)
KEROSENE	32,382,000	.018	.129	291	.014	.101	230
DISTILLATE	164,808,000	.018	.180	1,483	.043	.284	3,510
PROPANE	11,802,000	.009	.096	53	.000014	.00015	0
NATURAL GAS	539,000,000	.00008	.080	22	.0000006	.001	0
COAL	31,000	3.0	.111	47	38	1.400	586
WOOD	2,755,000	1.000	.056	1,378	.400	.022	551
TOTALS				3,273			4,877

COMBINED TOTAL = 26,103 82,062

*THE FOLLOWING UNITS OF MEASURE ARE USED:
KEROSENE, DISTILLATE, RESIDUAL OIL, AND PROPANE: GALLONS (CALCULATED USING 42 GALS/BARREL)
NATURAL GAS: STANDARD CUBIC FEET.
COAL: TONS.
WOOD: TONS(ASSUMING 2.5 TONS/CORD)

**A WEIGHTED AVERAGE OF 1.97% WAS USED FOR THE SULFUR CONTENT OF RESIDUAL FUEL OIL.

***AN ESTIMATED SULFUR CONTENT OF 2.2% WAS USED HERE FOR RESIDUAL FUEL OIL.

APPENDIX D

MOBILE3 SCENARIOS*

QUARTER	AVERAGE SPEED URBAN ROADS	AVERAGE TEMPERATURES (°F) NORTHERN ZONE	SOUTHERN/COASTAL ZONE
1	19 MPH	15	25
2	19 MPH	40	45
3	19 MPH	65	65
4	19 MPH	45	50

QUARTER	AVERAGE SPEED RURAL ROADS	AVERAGE TEMPERATURES (°F) NORTHERN ZONE	SOUTHERN/COASTAL ZONE
1	35	15	25
2	35	40	45
3	35	65	65
4	35	45	50

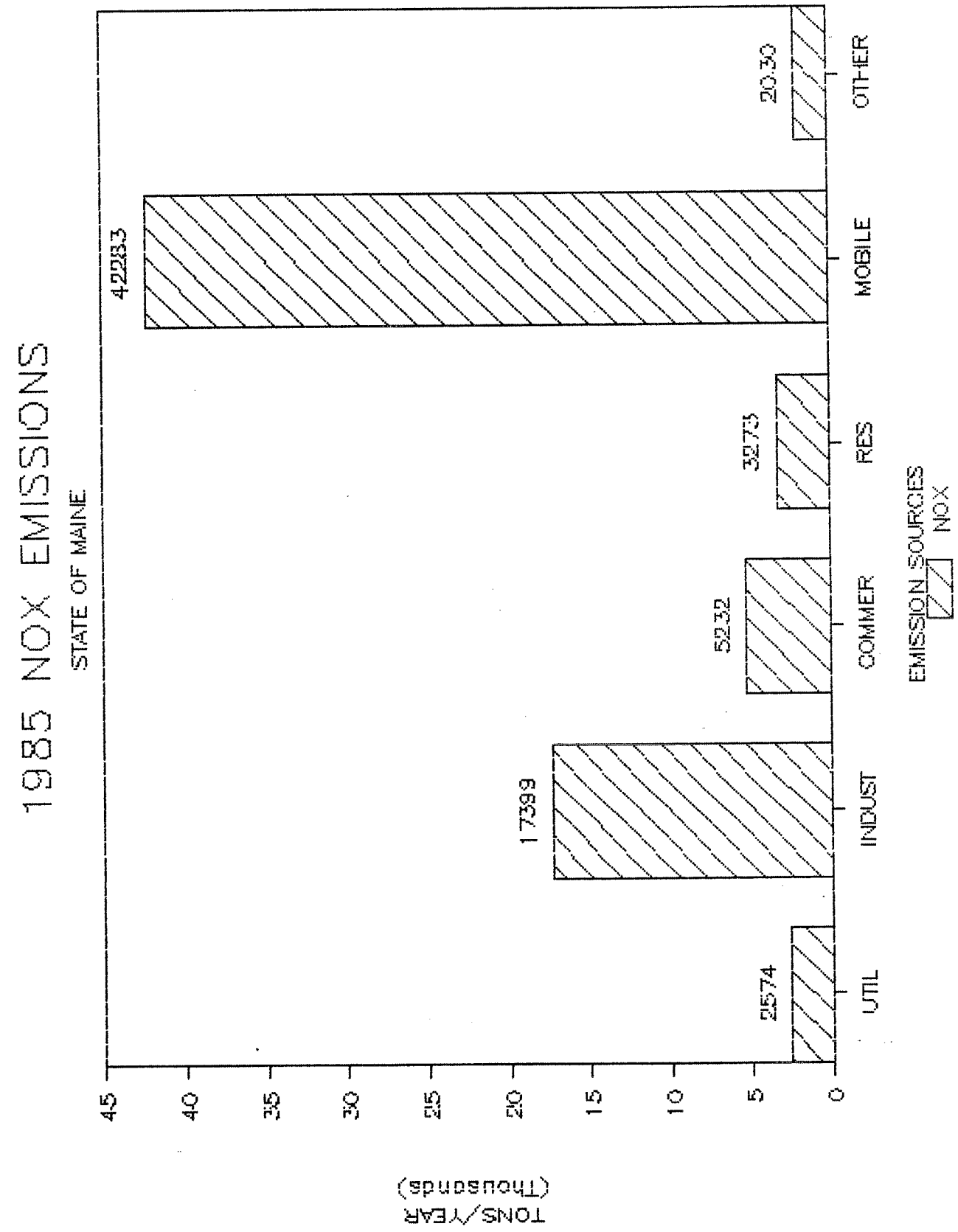
QUARTER	AVERAGE SPEED INTERSTATE ROADS	AVERAGE TEMPERATURES (°F) NORTHERN ZONE	SOUTHERN/COASTAL ZONE
1	55	15	25
2	55	40	45
3	55	65	65
4	55	45	50

*Used to calculate Mobile emission factors

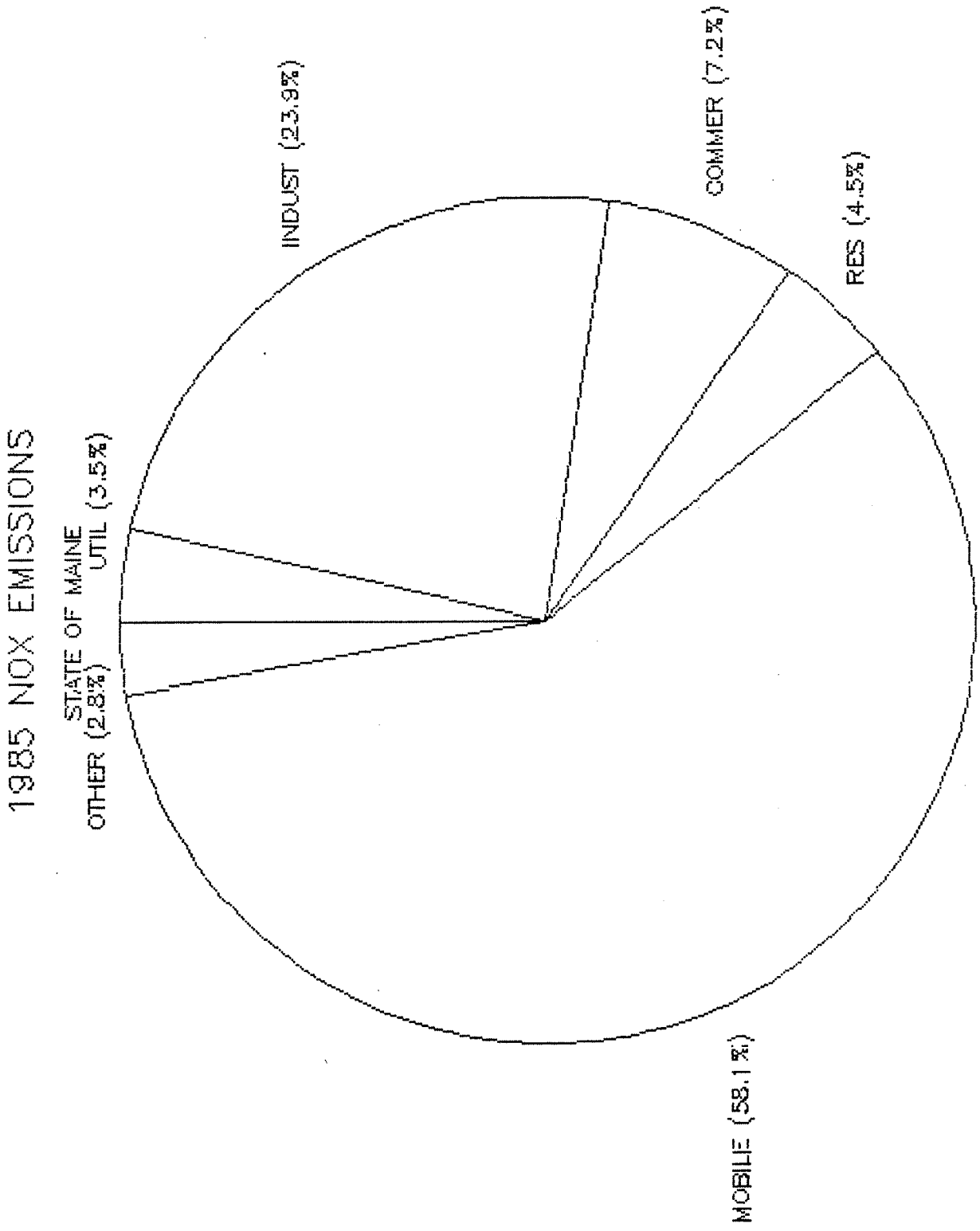
ESTIMATED MOBILE SOURCE NOX EMISSIONS
YEAR = 1985

COUNTY	PERCENT VMT	ANNUAL VEHICLE MILES (MILLIONS)	NOX EMISSIONS (TONS/YEAR)
ANDROSCOGGGIN	7.30	679.29	2965
AROOSTOOK	7.20	669.99	2925
CUMBERLAND	20.10	1870.39	8164
FRANKLIN	2.60	241.94	1056
HANCOCK	5	465.27	2031
KENNEBEC	9.70	902.62	3940
KNOX	2.50	232.64	1015
LINCOLN	2.70	251.25	1097
OXFORD	4.10	381.52	1665
PENOBSCOT	12	1116.65	4874
PISCATAQUIS	1.50	139.58	609
SAGADAHOC	2.40	223.33	975
SOMERSET	4.50	418.74	1828
WALDO	2.70	251.25	1097
WASHINGTON	3.20	297.77	1300
YORK	12.50	1163.18	5077
TOTAL	100	9305.40	40619

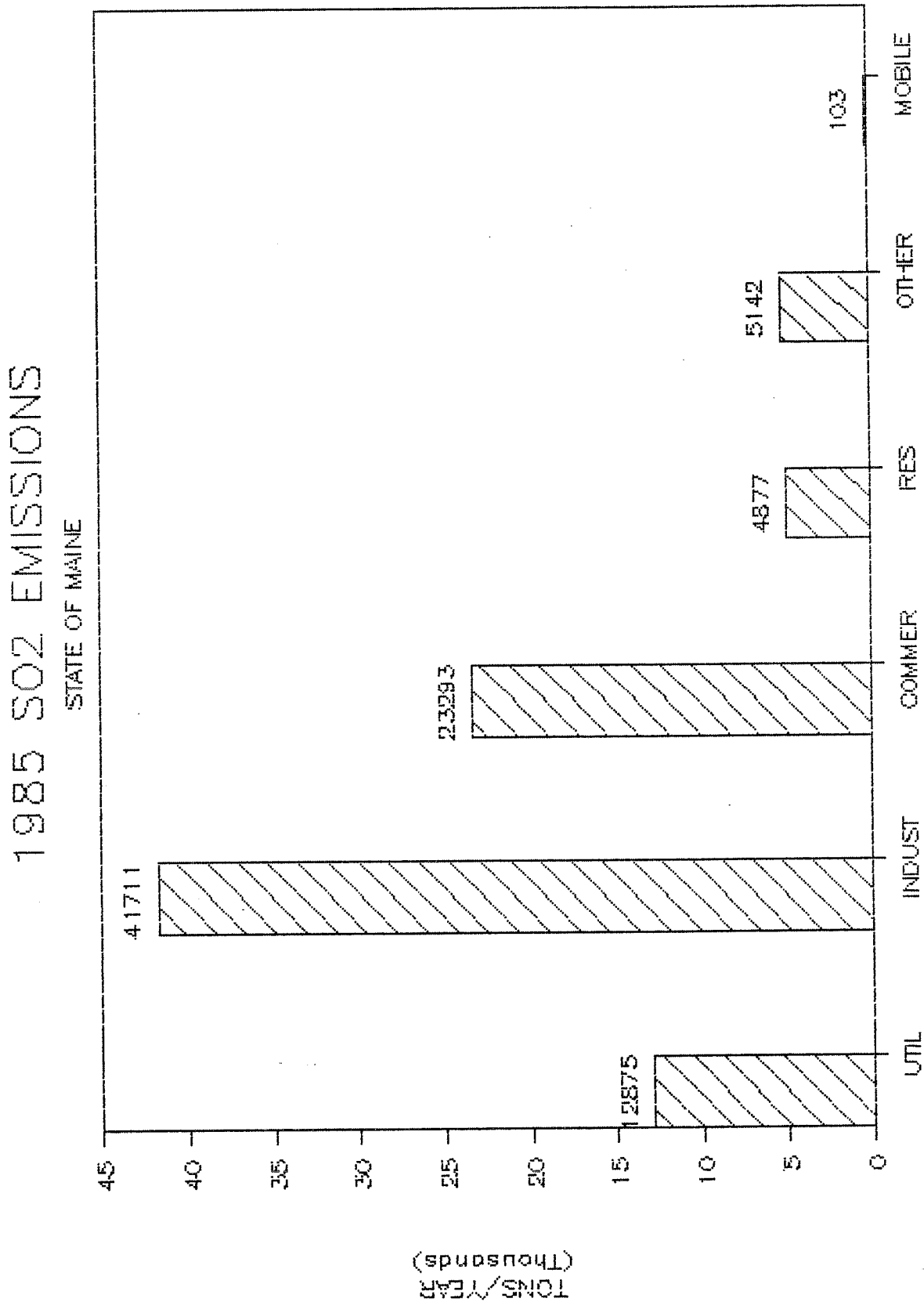
APPENDIX F


1985 NOX EMISSIONS
STATE OF MAINE
TONS/YEAR
(Thousands)
45
40
35
30
25
20
15
10
5
0
2574
17399
5232
32.73
42283
20.30
UTIL
INDUST
COMMER
RES
MOBILE
OTHER
EMISSION SOURCES
NOX

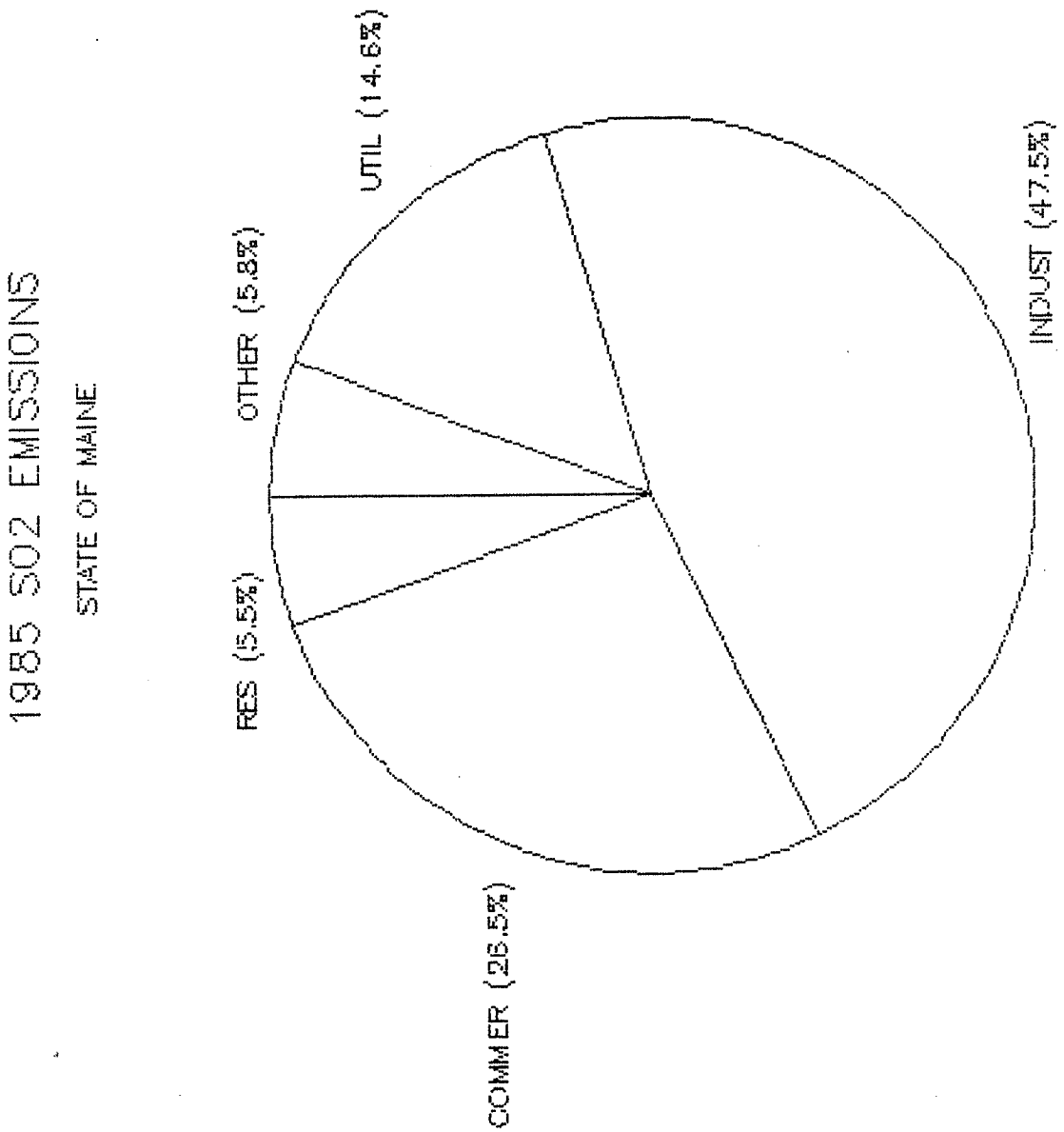
APPENDIX G


1985 NOX EMISSIONS
STATE OF MAINE
OTHER (2.8%)
UTIL (3.5%)
INDUST (23.9%)
COMMER (7.2%)
RES (4.5%)
MOBILE (58.1%)

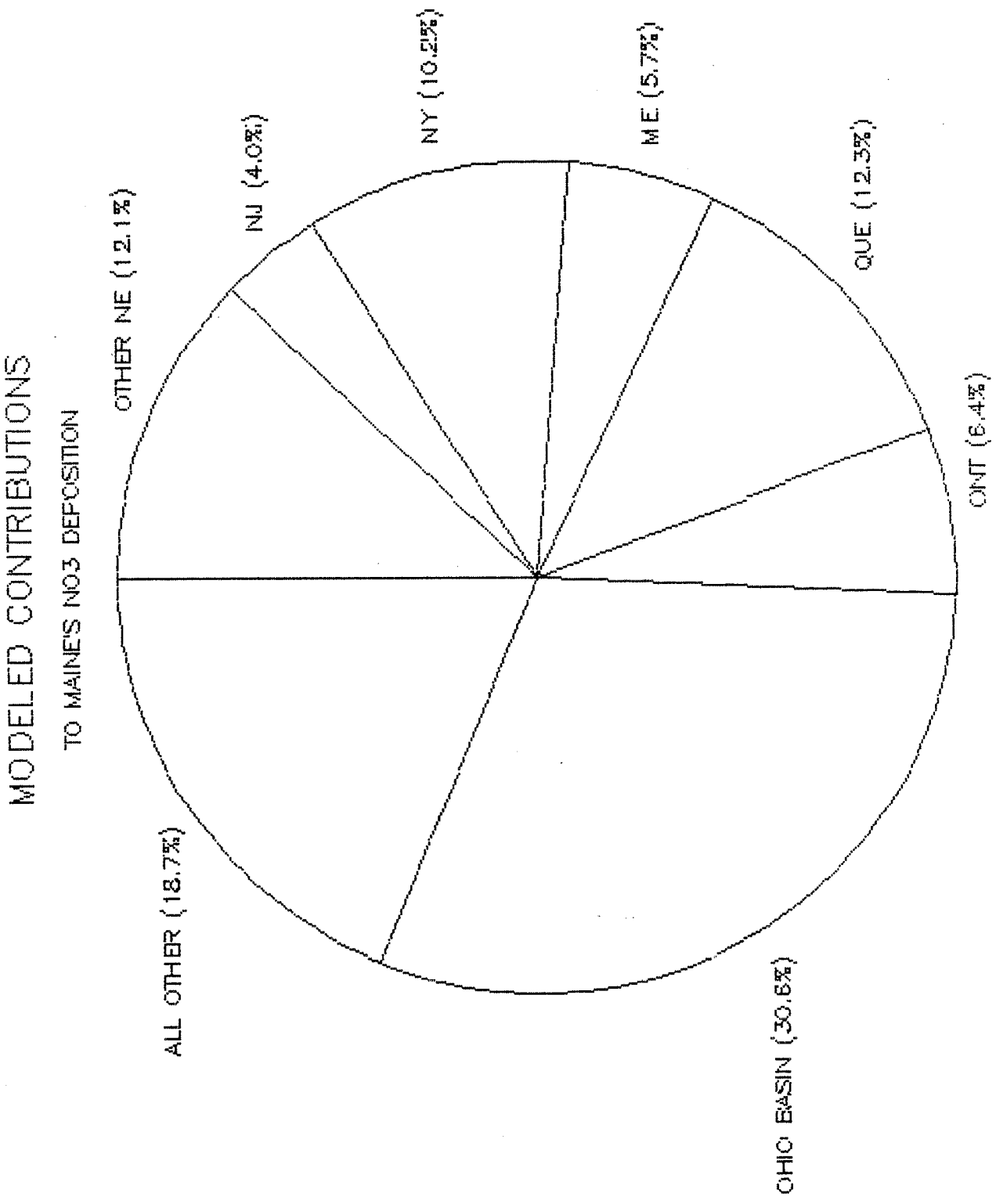
APPENDIX H


1985 SO2 EMISSIONS
STATE OF MAINE
TONS/YEAR
(Thousands)
45
40
35
30
25
20
15
10
5
0
12875
41711
23293
4877
5142
103
UTIL
INDUST
COMMER
RES
OTHER
MOBILE
EMISSION SOURCES
SO2

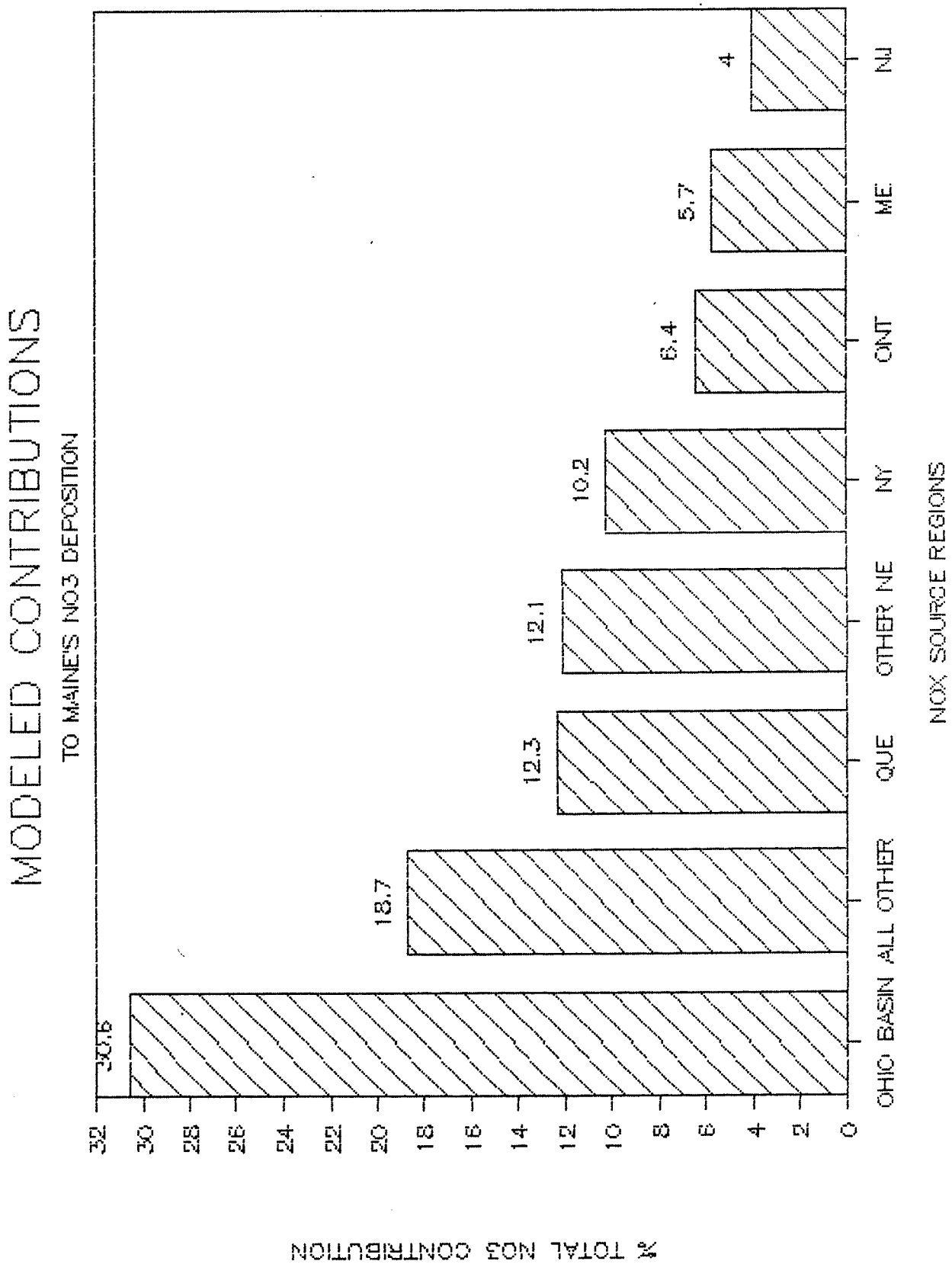
APPENDIX I


1985 SO2 EMISSIONS
STATE OF MAINE
UTIL (14.6%)
OTHER (5.8%)
RES (15.5%)
INDUST (47.5%)
COMMER (26.5%)

APPENDIX J


MODELED CONTRIBUTIONS
TO MAINE'S NO3 DEPOSITION
OTHER NE (12.1%)
NJ (4.0%)
NY (10.2%)
ME (5.7%)
QUE (12.3%)
ONT (6.4%)
OHIO BASIN (30.6%)
ALL OTHER (18.7%)

APPENDIX K


MODELED CONTRIBUTIONS
TO MAINE'S NO3 DEPOSITION
% TOTAL NO3 CONTRIBUTION
NOX SOURCE REGIONS
30.6
18.7
12.3
12.1
10.2
6.4
5.7
4
OHIO BASIN
ALL OTHER
QUE
OTHER NE
NY
ONT
ME
NJ
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

MODELED SULFUR DEPOSITION IN MAINE

TABLE OF CONTENTS

Introduction

Precipitation in the northeastern United States and eastern Canada is more acidic than normal. Monitoring data collected in Maine since 1979 indicates moderately acidified precipitation with recorded annual average pH as low as 4.35 (Gordon et al., 1985). The major component of acidic precipitation in Maine and in the eastern United States is sulfuric acid. This acid forms when sulfur dioxide (SO_2) released from electric utilities, industrial and smelting processes, and combustion of fossil fuels combine with moisture in the atmosphere. Because SO_2 emissions in Maine are relatively low compared with those in the remainder of the United States and Canada, sources outside the State are expected to be the major cause of acidic deposition within Maine. Much of the sulfur dioxide emitted into the air is converted to sulfates which is the predominant component of regional haze in the eastern United States.

Long-range transport models can be used to determine source-receptor relationships. These models are combinations of submodels which simulate physical and chemical processes involved in the transport of air pollutants over long distances. Simplifying assumptions are applied in the submodels because of impossibility of representing all atmospheric processes and physical parameters that affect transport in the physical environment. There are inherent limitations to the use of these models and in the associated emissions and meteorological data input to them. Uncertainties and errors cannot be determined because field and laboratory measurements are not used in evaluating impacts. Long-range transport models cannot provide accurate relationships between SO_2 emissions from a single source and sulfur deposition at a specific receptor site. However, the models can be used to determine the relative contributions made by regional groupings of sources to deposition at a receptor.

The staff at New York's Department of Environmental Conservation, ran a long-range transport model, for the benefit of the Maine DEP to compare the relative contributions of emissions from Maine sources and those from sources outside the State. In this way, modeled sulfur deposition levels in Maine and in the Maritime Provinces of Canada could be compared. The results of the modeling were also compared to measured deposition data to determine the effectiveness of the control of SO_2 emissions from Maine sources.

Modeling Methodology

Ontario's Ministry of the Environment's model (Venkatram et al., 1982), MOE, was utilized to determine the total sulfur deposition at selected receptors resulting from United States and Canadian SO_2 emissions. Nitrogen oxides were not considered in the analysis. The MOE model is a statistical model as the physical processes of transport, dispersion, and removal of pollutants are described in terms of statistical parameters. The model estimates long-term concentrations assuming they are insensitive to short-term fluctuations in meteorology. Mean values of the large scale meteorology are used to calculate annual average concentrations and deposition. A constant 1000-meter mixing height is used, and a mean westerly flow of 10 meters per second (m/s) is assumed as a first approximation by the model. Though simplistic, it is broadly reasonable since mid-latitude weather systems generally move from west to east. Horizontal dispersion coefficients are expressed as a constant function of travel time from the source. Values of 10 m/s and 6 m/s are assumed for the horizontal velocity fluctuations of synoptic turbulence.

Pollutant particles are classified in the model as wet and dry, with wet particles existing during precipitation and dry particles during dry periods. The percentage of time precipitation occurs along the paths of the trajectories are based upon climatological data. Wet removal rates of $3x10^{-5}s^{-1}$ and $1x10^{-4}s^{-1}$ are assumed for SO_2 and sulfates (SO_4), respectively. Dry deposition is represented by use of a constant deposition velocity of $0.5x10^{-2}$m/s for SO_2 and $0.05x10^{-2}$ m/s for SO_4. For both wet and dry periods, a transformation rate of SO_2 to SO_4 of 1% per hour is assumed.

The MOE model is a linear model. The change in deposition at a receptor is directly proportional to the change in emissions. Although there is some controversy over the linearity between emissions and deposition, the MOE model was the only model available for this analysis. Venkatram et al. (1982) provide a more detailed discussion of the model.

Nine hundred tons or greater SO_2 sources in Maine were modeled individually at their actual locations. Specific stack parameters, such as height and volumetric flow, were not employed in the modeling. Sources were treated as ground-level release points, and instantaneous mixing was assumed. Therefore the MOE model is likely to overpredict the impact of local sources. Smaller sources of SO_2 located in Maine were modeled as area sources and apportioned by county. Sources outside of Maine were assigned to rectangular grids. Impacts calculated for individual sources, counties, and grids were summed to estimate the contribution of each state and province to deposition at selected receptors.

Emission Inventory

The year 1980 was selected for the base case because of the availability of an SO_2 emissions inventory for that year. Maine's emissions were projected to 1990 assuming with the current 2.5% ceiling no additional controls, and also assuming a 2.0% sulfur limitation. Emissions for other states and for the Canadian provinces were not projected to 1990 due to insufficient information and the need to evaluate the effect of changes in Maine's emissions. Modeling was performed to determine the effect of these emission changes on sulfur deposition.

The 1980 emissions inventory compiled under the United States-Canada Memorandum of Intent on Transboundary Air Pollution (1983) was used for all SO_2 emissions from both countries, except those from Maine. Emissions from forty states and the District of Columbia and nine adjacent Canadian provinces were input to the model. Only the western-most states and provinces were excluded.

Table 1 lists the SO_2 emissions for each state and province, included in the analysis. Emissions from the United States and Canada totaled 26,687 kilotons of SO_2 for 1980 of which approximately 83% from the United States. Emissions from the NESCAUM - member states (Northeast States for Coordinated Air Use Management, which includes the New England states plus New York and New Jersey) totaled 1701 kilotons, or 7.7% of the United States emissions and 6.4% of the U.S./Canadian SO_2 emissions. Emissions from the New England states totaled 592 kilotons, or 2.7% of the U.S. emissions and 2.2% of the U. S. and Canadian emissions. Maine's contribution for 1980, 110 kilotons, was approximately 0.5% of the total U.S. emissions, and 0.4% of the total emissions from the United States and Canada.

Table 2 summarizes the SO_2 emission sources in Maine. Emissions were projected to decrease 9% by 1990 if no additional controls are required, or 23% if a 2.0% sulfur limitation is imposed.

In addition to fuel-burning emissions summarized in Table 2, 3500 tons/year of SO_2 process emissions were input to the model. These emissions result from Great Northern Paper Company's sulfite and MgO recovery processes. Another large source of SO_2 process emissions in the State, Delta Chemicals, Incorporated, located in Searsport was not included in the emissions inventory, or the modeling. In 1980 approximately 990 tons of SO_2 were released from the Delta Chemicals plant (Brooks, 1985).

For the purposes of modeling, a major point source was defined as a source emitting more than 900 tons or greater of SO_2 in 1980. Figure 1 shows the locations of the 21 largest sources in Maine, considered individually in the modeling. (They are not numbered by size, but are listed following the order given in Table 2.) Table 3 shows the total emissions for point sources and area sources for each of the three scenarios modeled and the percent contributions to the total emissions. Major point sources contributed approximately 80% of Maine's SO_2 emissions in 1980. Their relative contribution will decrease by 1990 because of projected biomass projects. If a 2.0% sulfur in fuel limitation were imposed another 14,732 ton reduction could be realized.

Champion International Corporation in Bucksport and James River-Otis, Incorporated in Jay were not modeled at their actual locations. The effect of this error was estimated and is discussed later.

The emissions inventory for Maine was further divided into four categories of SO_2 emissions - distillate sources, major point sources of oil (plus process emissions), non-point sources of oil, and coal sources. The total emissions and percent contribution of each category are shown in Table 4 for the 1980 base case, for 1990, and for 1990 assuming a 2.0% sulfur limitation. For each scenario, majority of emissions are from major point sources of oil. While coal emissions were insignificant in 1980, their contribution is expected to increase to 10% in 1990.

Receptors

Because the model assumes general westerly flow, the greatest impacts will occur east of the selected emission sources. Thus, the receptors chosen for predicting sulfur deposition were located in Maine and generally east of the State, mainly in the Maritime Provinces of Canada. The existing acidic deposition monitoring sites in Maine at Bridgton, Bar Harbor (at Acadia National Park), Greenville, and Caribou were four of the five Maine receptors. Use of these sites allows model results to be correlated with measured data to estimate Maine's share of controls required to meet anticipated target values of sulfate deposition. The fifth Maine receptor was placed at Mt. Katahdin in Baxter State Park. Five receptors were chosen in New Brunswick and six in Nova Scotia, these eleven receptors were also located at monitoring stations. Three additional receptors were placed in Newfoundland and Quebec. The 19 receptor locations at which sulfur deposition was calculated by the model are shown in Figure 2.

Figure 3 shows the locations of the four existing sites in Maine at which precipitation chemistry is monitored. These sites were originally selected for monitoring to ensure overall coverage of the State, including areas thought to be sensitive to acidic deposition. The Bar Harbor, Bridgton, and Greenville stations are located in high sensitivity regions (Gordon et al., 1985). Caribou is not in a highly sensitive region. It was selected to have a site in the northern part of Maine. Comparison with the major point sources of SO_2 in Maine shown in Figure 1 indicates that, the Bar Harbor site, located downwind of many Maine sources under conditions most conducive to sulfate transport and deposition. Therefore, it best reflects the maximum modeled contribution of Maine sources to acidic deposition in Maine. The data collected at Bar Harbor may include the impact from some SO_2 sources in Maine, the data are complicated by the proximity of the site to the coast.

Two stations in New Brunswick, Grand Manan Island and Frog Lake, are likely to be impacted by Maine sources. These sites are located relatively close to the Maine border and no large Canadian sources are expected to significantly impact these stations when prevailing winds are south to west (Tims, 1985). Therefore, impacts predicted at these locations will be reasonably representative of sulfur deposition in eastern Maine.

Model Results For 1980

Figures 4 and 5 show the contributions to total sulfur deposition of Maine sources, other U.S. emissions, and Canadian sources for the 1980 base year at each of the 19 receptors. The first figure gives the contributions in absolute values, while the second indicates the percent contributions. The greatest impacts were predicted at the Bridgton site. Impacts at Acadia and Greenville were roughly equivalent and only slightly less than that predicted at Bridgton. Within Maine, the lowest predicted impact occurred at the Caribou site. Although Maine's emissions were only 0.4% of the total emissions input to the model, Maine's contribution to total sulfur deposition at all receptors ranged from 1 to 7%, varying from 3 to 7% at Maine receptors, Frog Lake, and Grand Manan Island. The maximum contribution of 7% occurred at Acadia National Park and at Frog Lake. Because a mean westerly flow is assumed and receptor 7 shows a contribution for Maine almost as great as the receptor at Acadia, Maine's maximum contribution may be greater at a receptor between Bangor and Eastport. The smaller contributions at Caribou, Greenville, Bridgton, and Mt. Katahdin were expected since these sites are upwind of Maine's largest SO_2 sources.

However, the maximum contribution to sulfur deposition within the State is estimated at 8% based on corrections for Delta Chemicals and Champion International.

Figure 5 and estimates for impacts from Delta Chemical and the Champion increase the estimate of the increase the contribution from Maine sources to sulfur deposition in New Brunswick to 5 to 8%. Maine's maximum contribution occurred at Frog Lake. Maine's contribution to deposition in Nova Scotia ranged from 2 to 4%, with a maximum at East Kemptville.

As previously mentioned total modeled emissions were 83% from U. S. sources and 17% Canadian sources. Figure 5 shows that these U. S. emissions contributed 40 to 65% of the sulfur deposition predicted in Maine, with the largest percentages occurring at Acadia and Bridgton. At these two receptors and at Grand Manan Island and Frog Lake, the contribution from U.S. sources exceeded that from Canadian sources. In the more northern areas of the State, i.e., at Caribou, Greenville, and Mt. Katahdin, the contribution from Canadian SO_2 emissions was larger than that from U.S. emissions.

Maine's contribution to sulfur deposition within the State can be broken down into the major point source and the area source portions. Major point source impacts include those from the 21 sources modeled individually. All other sources are considered area sources. The percent contribution of major point and area sources to total deposition at selected receptors is given in Table 5. Major point sources alone accounted for 65 to 86% of the impact. At all receptors, the major point source contribution far exceeded the contribution from area sources. These results as approximately 80% of Maine's SO_2 emissions in 1980 were emitted from the major point sources.

The contribution from each of the four categories of Maine sources - distillate, major point (oil plus process), oil non-point, and coal - can also be distinguished. Table 6 shows the contribution of each source category to sulfur deposition from Maine at selected receptors. The major point sources of oil were the largest contributors to sulfur deposition. There were no contributions from coal sources because emissions were assumed to be insignificant in 1980.

Figures 6 through 24 show the percent contribution to total sulfur deposition of various source regions for each of the 19 receptors. Each chart indicates the contribution from SO_2 sources in Maine, the remainder of New England, New York and New Jersey combined, the Mid-Atlantic states, the Southeastern states, the Midwest, the states of Pennsylvania, Ohio and West Virginia combined, the rest of the U.S., Quebec, Ontario, eastern Canada, and western Canada. These catagories were selected to allow for easy comparison with work previously completed by staff at New York's Department of Environmental Conservation (1984). The additional impact due to St. Regis and Delta Chemicals was not considered in this analysis.

Figures 6 through 10 demonstrate that Canadian emissions are large contributors to total sulfur deposition at Maine receptors. The contribution from Ontario and Quebec alone represented a minimum of 29% at Acadia to a maximum of 47% at Mt Katāhdin and 46% at both Caribou and Greenville. The second largest source region at Maine receptors were the Midwest plus Pennsylvania, Ohio and West Virginia whose contribution ranged from 26% at Caribou, Greenville, and Katahdin to 35% at Bridgton. The maximum contribution from New York, New Jersey and New England combined occurs at Bridgton at 20% and declines steadily towards more northerly and easterly receptors. Canadian sources contribute greater than 50% at Mt. Katahdin and Caribou, while Canadian sources contribute 49% at Greenville.

At Acadia and Bridgton, the New England contribution without Maine was 7%, while New York and New Jersey accounted for 17% of the deposition at Acadia and 16% at Bridgton. Approximately 25% of the deposition at these two sites resulted from NESCAUM states° emissions, including those from Maine. New England alone was responsible for 14% of the deposition at Acadia and 10% at Bridgton. At Caribou, Greenville, and Mt. Katahdin, Maine°s contribution was 4 to 5%, while the remainder of New England contributed 3% and New York and New Jersey accounted for 6 to 7%. Thus, the total contribution from New England at these sites was 7 to 8% and that of the NESCAUM states, 13 to 15%. At Grand Manan Island and Frog Lake (also considered representative of sulfur deposition in Maine), the New England contribution was estimated at 13% and 11%, respectively. The NESCAUM states accounted for 22% of the sulfur deposition at Grand Manan Island and 18% at Frog Lake. Table 7 shows the percent contribution from each of the NESCAUM states to total deposition at selected receptors. Excluding Maine, New York°s impacts were the largest of the NESCAUM states for most of the selected receptor locations.

Other source areas in the U.S. which made relatively large contributions to the predicted sulfur deposition at the 7 selected receptors (5 Maine sites plus Grand Manan Island and Frog Lake) were the Midwest (Indiana, Michigan, Illinois, Minnesota and Wisconsin). The Midwest accounted for 11 to 14% of the deposition, and the region consisting of Pennsylvania, Ohio, and West Virginia, contributing 14 to 21%. Each of these regions accounted for 18 to 19% of the total emissions input to the model. The largest contributions from each of these source areas were found at Bridgton.

The largest Canadian contributors at these receptors were Quebec and Ontario. Quebec°s contribution ranged from 14 - 16% at Bridgton, Acadia, and Grand Manan Island to 29 to 30% at Caribou, Greenville, and Mt. Katahdin. Emissions from Ontario accounted for 14 to 17% of the sulfur deposition at the 7 sites.

The New York DEC also used the MOE model to determine local versus out-of-state contributions to annual sulfur deposition. New York State°s maximum contribution in the Adirondacks was 17%. Other sources in the rest of the United States contributed slightly more than 50%, while Canada contributed as much as 33%.

At the receptors in New Brunswick and Nova Scotia, the eastern Canadian contribution was much larger than that at Maine sites. In almost all instances, U. S. source groups, excluding Maine, contributed the same amount or less to sulfur deposition at New Brunswick receptors than at Maine locations. At Nova Scotia receptors, the rest of New England, the Midwest states, and the Pennsylvania/Ohio/West Virginia region sometimes made larger contributions. Although the contribution of Maine sources was less in Nova Scotia than in Maine, it was generally higher at New Brunswick receptors.

Vermont's Implementation Plan for the Protection of Visibility in the State of Vermont (1985) contains results of annual sulfate modeling using a model developed by Dr. James Fay referred to as the Fay/Rosenziverg model. The results for Maine are presented in Table 8 along with those of the MOE model. The percent contributions by various states to deposition in Maine are very similar.

Model Results For 1990

The sulfur deposition predicted from Maine sources at each receptor is shown in Table 8 for 1980 and for 1990 with and without a sulfur limitation. Also shown are the percent reductions in deposition from Maine sources over the 1980 base case for each of the 1990 scenarios. For the 1990 case with no additional sulfur controls, the reductions in sulfur deposition from Maine sources at Maine sites ranged from approximately 1% at the Acadia receptor to 18% at Caribou. With a 2.0% sulfur limitation, the reductions ranged from 16% at Acadia and Bridgton to 30% at Caribou. The large reduction at Caribou is due to the strong influence of Fraser Paper Company. Eighty percent of the reduction in Maine's impact at Caribou results from the reduction in emissions at Fraser. However, these percentages represent only small absolute reductions. Because of the relatively small amount of sulfur deposition resulting from Maine sources, the 23% reduction in SO_2 emissions resulting from imposition of a 2.0% sulfur limitation would reduce Maine's at most by only slightly more than one-tenth of 1 kilogram per hectare.

Table 10 shows the percent contribution of Maine sources to total predicted sulfur deposition for each of the 1990 cases as compared with the 1980 results. If Delta Chemicals had been included in the analysis and Champion Paper Company had been modeled at its proper location, the percent contribution at the worst-case receptor in Maine, Acadia National Park, would have been roughly 0.9% higher in 1990 and 0.8% higher in 1990 assuming a sulfur limitation were imposed. Maine's percent contribution is predicted to be reduced by 1% with the imposition of a 2.0% sulfur limitation. Maine's contribution will be relatively more in 1990 once reductions from New York, Massachusetts and other programs are included in the calculations.

The percent reductions in predicted total sulfur deposition achieved by SO_2 emission reductions in Maine are shown in Table 10 for selected receptors. The Maine emissions reductions expected by 1990 would reduce total deposition in Maine by less than 1%. The 23% reduction in emissions which would be obtained with imposition of a 2.0% sulfur limitation would reduce the total deposition by 2%.

The contribution of major point sources including oil, coal, and process sources versus area sources to deposition predicted from Maine was available only for the 1990 case with no additional controls. The percent contributions are shown in Table 12 for each of the receptors in Maine and for Frog Lake and Grand Manan Island. A comparison of these values with those in Table 5 indicates that by 1990 the contribution from major point sources will be reduced, although the majority of sulfur deposition will still eminate from these sources.

The percent contribution of the four categories of Maine sources to sulfur deposition from Maine are shown in Table 13 for each of the 1990 cases for selected receptors.

Measured Sulfate Deposition

Monitoring of precipitation chemistry began at Greenville, Maine in 1979. Currently, precipitation is being collected weekly at four stations located in Bridgton, Bar Harbor, Greenville, and Caribou. The samples are analyzed for pH and then sent to Illinois for a detailed chemical analysis. Based upon the resulting sulfate values, the volume of wetfall in the sampler bucket, and the precipitation measured in the rain gauge, annual wet sulfate deposition was calculated for each site.

A reasonably complete data base to calculate the annual sulfur deposition was available for two years (1982 and 1983) for each of the four sites. Substitutions were made where possible for missing data, and depositions were adjusted to estimate yearly values.

Sulfate data for Bridgton and Bar Harbor were adjusted for sea spray to determine excess (continental or non-marine) sulfate since sea salt aerosols raise the concentration of sulfate and other ions when they enter precipitation samples. Sulfate associated with sea spray is generally not complexed with hydrogen ions, and thus does not add to the acidity of the precipitation (Tims, 1985).The amount of marine sulfate was defined as the product of the chloride (or magnesium) concentration determined in each sample and the ratio of sulfate to chloride (or magnesium) in bulk sea water. Ratios of 0.10344 and 0.553223 were assumed for chloride and magnesium, respectively (ENB, 1985; Tims, 1985). Each chloride (or magnesium) sample was multiplied by the appropriate ratio for bulk sea water and subtracted from the measured sulfate.

This method for determining excess sulfate assumes all the magnesium and chloride in the precipitation sample are assumed to result from sea spray.that the ratios of sulfate to magnesium and sulfate to chloride in bulk sea water are the same as those in the marine aerosols entering the sample. Although this assumption is somewhat questionable, it is the most practical at the present time. It is reasonable based upon available data from inland and coastal sites. However, it becomes less valid with distance from the coast and with the presence of other sources such as road salt. For this reason, corrections for marine aerosols were made only to data collected at sites within 100 km of the coast, i.e., at Bridgton and Bar Harbor, following Environment New Brunswick policy (Tims, 1985) and the recommendation of the

Unified Deposition Data Base Committee (1985). The sulfate deposition values, once corrected for marine aerosols, result entirely from anthropogenic sources. Other natural emissions are expected to be very small relative to anthropogenic emissions, but there are large uncertainties in the magnitude of emissions from natural sources.

Annual wet sulfate deposition rates for each of the monitoring sites in Maine are shown in Table 14. The highest deposition levels occurred at Bar Harbor, except in 1984 Yearly values were equal to or less than 20 kilograms/hectare (kg/ha) at all sites, except Bar Harbor, where the maximum annual value was 24 kg/ha in 1981. Uncorrected total deposition values for Bar Harbor and Bridgton are indicated in parentheses in the table. The sea spray correction was greater for Bar Harbor because the site is much closer to the ocean than Bridgton. For the Caribou and Greenville stations, excess sulfate and total sulfate are equivalent. Deposition rates for Frog Lake and Grand Manan Island stations in New Brunswick are also shown in the table (Tims, 1985). Although excess sulfate deposition values for these locations were also based upon measured magnesium and chloride. The deposition rates are not directly comparable to those for Maine sites as calculation methods were not identical. All of the sulfate deposition rates calculated from measured data are presented in kilograms per hectare per year.To compute the equivalent sulfate deposition (as SO_4) in kg/ha/yr predicted by the MOE model, the sulfur deposition values in Figure 4 should be multiplied by a factor of three, which represents the relative molecular weights of sulfur and sulfate as SO_4. The predicted values may then be compared with measured annual deposition values presented in Table 13. It is not proper to make a direct correlation because the data involves different years, non specific meteorology inputs and total versus wet deposition nor is the model designed to be used as an absolute predictor. However, the relative magnitude of these data lends credibility to the method and assumptions.

The quantity of wet sulfate deposition accumulated over a year is largely dependent upon the amount of precipitation which falls during that time. Yearly precipitation values may vary widely due to year to year variability of meteorology. Table 15 shows the amount of precipitation recorded at the deposition sites for the years used to determine annual sulfate deposition rates. At Bridgton, Greenville, and Bar Harbor, the 1982 and 1983 precipitation values differed by more than 25 inches, or nearly 50%. Precipitation data were incomplete each year at each site. Although only 1 or 2 weeks' data were missing each year at Bar Harbor, as many as 8 weeks data were missing at Bridgton. However, the number of weeks of missing data were relatively consistent from year to year at each site. Despite missing data, comparison of annual precipitation levels recorded at an individual site can provide some indication of year-to-year variability.

To make the sulfate deposition measurements more representative of average meteorological conditions and reflect long-term deposition levels, the yearly wet deposition rates were averaged for each site. Then the were adjusted to the 30-year average precipitation for each location, following procedures used previously by the New York Department of Environmental Conservation (1984). Averages were obtained by summing all the weekly depositions and divides by the total sample volume over the entire period. The volume weighted average was tehn multiplied by the total precipitation over the entire period. The 2, 3, or 4 year average to obtain the 30-year precipitation adjusted values.

Although 30 years of data have not been recorded at the Bridgton, Bar Harbor, and Greenville monitoring sites; data were available from locations very close to the stations within these towns. Table 16 shows the 30-year average precipitation values calculated from data recorded in Baron et al. (1980). Because of the incomplete records at the monitoring sites, comparison of yearly precipitation with the 30-year averages is difficult. However, despite missing data, the total precipitation recorded at each site in 1983 was substantially greater than the long-term averages at the same locations. The coefficients of variation over the 30 years, also shown in Table 16, may indicate that annual wet deposition values computed from 1983 measured data may be a 15 to 18% greater than the 30-year weighted average.

Deposition Targets

Preliminary scientific evidence suggested that a wet sulfate deposition rate of 20 kg/ha/yr would be adequate to protect all but the most sensitive aquatic ecosystems in North America. This level was proposed by the Canadian members of the Impact Assessment Working Group established under the United States-Canada Memorandum of Intent on Transboundary Air Pollution (1983). However, a recent study by Gorham et al. (1984) indicates that a target loading of 20 kg/ha/yr may produce an average pH below the 4.6 to 4.7 threshold level for damage to aquatic ecosystems. Their analysis showed that target values of 14 to 16 kg/ha/yr of wet sulfate deposition are probably necessary to produce these pH values. These target threshold values are based upon wet rather than total deposition because a larger data base is available to evaluate ecological effects.

Annual wet sulfate deposition rates for Caribou, Greenville, and Bridgton have been at or below 20 kg/ha/yr. Although deposition rates exceeded this level at Bar Harbor for 3 of the 4 years analyzed, the 4-year average, adjusted for 30 year average precipitation, was only 18 kg/ha/yr. This value is equivalent to the 3-year average at Bridgton. The 2-year average precipitation-adjusted values at Caribou and Greenville were 13 kg/ha/yr.

The percent reductions in sulfate deposition needed to reach target values of 14 and 16 kg/ha/yr at Bridgton and Bar Harbor are shown in Table 16. Deposition levels are a concern at both of these sites because they are located in areas sensitive to acidic deposition. Reductions of about 11 and 22% would be required to achieve target levels of 16 and 14 kg/ha/yr, respectively. If other contributions to background concentrations, such as those resulting from the decomposition of organic matter or the bacterial reduction of sulfate, are not insignificant, the percent reductions in man-made SO_2 emissions needed to reach the target levels would be greater.

Also listed in Table 16 is Maine°s contribution to the total (wet plus dry) deposition at the Bridgton and Bar Harbor stations based upon the MOE model results. Predicted total deposition values are compared to measured wet deposition for several reasons:

1) Measured total deposition cannot be used because dry deposition samples collected at the monitoring sites have not yet been analyzed.

2) Lack of dry deposition data also precludes the evaluation of the model°s accuracy in determining wet versus dry deposition.

3) Galloway and Whelpdale (1980) found that wet and dry deposition are approximately equivalent in eastern North America. However, the ratio of dry to wet deposition generally decreases with increasing distance from source regions, because more of the emitted sulfur has been converted to sulfate.

4) A recent study by Shaw (1982) indicated that wet deposition accounts for 80 to 90% of the total deposition in the Atlantic Provinces of Canada. It is expected that the ratio of wet to total deposition in Maine corresponds more closely to these latter percentages. Basing sulfur dioxide controls on total rather than wet deposition results in conservative estimates. Emission reductions would be expected to reduce both wet and dry deposition.

Maine°s portion of the reductions needed to reach 14 and 16 kg/ha/yr at the Bridgton and Bar Harbor monitoring sites are shown in Table 16. Maine°s target value can be defined as a product. The two factors are of the percent reduction required to attain the threshold level based upon measured wet sulfate deposition and Maine°s contribution to the total deposition based upon the model. This procedure follows New York State Department of Environmental Conservation (1984) study.

In each case, Maine°s portion is less than 2%. The modeling indicates that the 9% reduction in Maine°s SO_2 emissions expected by 1990 with no additional controls would result in less than a 0.08% reduction in total sulfate deposition (based upon the modeling). This reduction is substantially less than Maine°s portion as defined above for either site for target values of 14 and 16 kg/ha/yr. The imposition of 2.0% sulfur limitation by 1990 would result in a 23% reduction in SO_2 emissions. This would produce emission deposition reductions slightly exceeding Maine°s share at each site based upon a goal of 16 kg/ha/yr. Additional controls would be required for Maine to achieve its portion of the reduction needed to attain a 14 kg/ha/yr target.

Summary

The Ontario Ministry of the Environment°s MOE model was used to estimate relative contributions of 1980 SO_2 emissions from various source regions to sulfur deposition in Maine and in the Maritime Provinces of Canada. The Midwest (Indiana, Michigan, Illinois, Minnesota, and Wisconsin) and the Pennsylvania/Ohio/West Virginia area made relatively large contributions to sulfur deposition in Maine. The provinces of Ontario and Quebec were also important source regions. The maximum contribution of Maine sources to deposition within the State was approximately 8%. The majority of this impact resulted from the 21 largest sources of SO_2 in Maine.

Modeling was also performed to determine the effect of SO_2 emission reductions in Maine on sulfur deposition. The impact of 1990 emissions were analyzed with and without a 2.0% sulfur limitation. The 9% reduction in emissions expected by 1990 with no additional controls resulted in a 1 to 18% reduction in Maine°s impact within the State. The 23% reduction expected if a

2.0% sulfur limitation were imposed produced 16 to 30% reductions. However, total predicted sulfur deposition was reduced by less than 1.5% at Maine receptors even with the sulfur cap.

Annual sulfate deposition was calculated from data collected at Caribou, Greenville, Bar Harbor, and Bridgton. At the latter two sites, deposition values were corrected for marine aerosols. Corrected yearly values were at or below 20 kg/ha at all sites except Bar Harbor. To account for the variability of meteorology and make the deposition measurements more representative of long-term levels, yearly deposition rates were averaged and adjusted to the 30-year average precipitation at each location. Precipitation-adjusted average deposition values were 13 kg/ha for Caribou and Greenville and 18 kg/ha for Bridgton and Bar Harbor.

The reduction in SO_2 emissions needed to reach target values of 14 and 16 kg/ha/yr were determined for the Bar Harbor and Bridgton stations, both located in areas thought to be sensitive to acidic deposition. A 22% reduction would be required to meet a 14 kg/ha/yr target, or an 11% reduction would be required to meet a 16 kg/ha/yr level. Maine°s portion of the needed reduction was based upon the State°s contribution to sulfur deposition as predicted by the model. To meet a 16 kg/ha/yr target level, Maine°s emissions reduction expected by 1990 is not sufficient to meet their portion of required reduction. However, Maine°s portion would be achieved with imposition of a 2.0% sulfur limitation. Additional controls would be required to accomplish Maine°s share with a 14 kg/ha/yr target. Significant SO_2 emission reductions from sources outside the State would be necessary in addition to local controls to meet either target level within Maine.

LITERATURE CITED

Baron, W. R., D. C. Smith, H. W. Borns, Jr., J. Fastook, and A. E. Bridges, 1980: Long-time Series Temperature and Precipitation Records for Maine, 1808-1978. Life Sciences and Agricultural Experiment Station, University of Maine at Orono, 254p.

Brooks, J., 1985: Memorandum on Delta Chemicals, Inc., emissions calculations. Department of Environmental Protection, Augusta, Maine.

Environment New Brunswick (ENB), 1985: Saint John Sulfate Deposition Study; Interim Report for the Period Aug. 31 - Dec. 31, 1984. Environmental Services Branch. Technical Report No. T-85.

Galloway, J. N. and D. M. Whelpdale, 1980: An atmospheric sulfur budget for eastern North America. Atmos. Environ. 14: 409-417.

Gordon, N. J., J. S. Williams, and G. Flatebo, 1985: Acid Rain in Maine. Maine Department of Environmental Protection with the State Planning Office, 29p.

Gorham, E., F. B. Martin, and J. T. Litzau, 1984: Acid rain: Ionic correlations in the eastern United States, 1980-1981. Science 225: 407-409.

Maine Department of Environmental Protection (MDEP), 1984: Sulfur dioxide emissions inventory; executive summary.

New York State Department of Environmental Conservation (NYDEC), 1984: Draft Environmental Impact Statement for Policy on Sulfur Dioxide Emissions (Statewide).

Shaw, R. W., 1982: Deposition of atmospheric acid from local and distant sources at a rural site in Nova Scotia. Atmos. Environ. 16 :337-348.

Tims, J. 1985: Personal communication. Environment New Brunswick, Fredericton, N.B., Canada.

Unified Deposition Data Base Committee, 1985: A Unified Wet Deposition Data Base for Eastern North America: Data Screening, Calculation Procedures, and Results for Sulphates and Nitrates (1980). Prepared for the Canadian Federal-Provincial Research and Monitoring Co-ordinating Committee, 118p.

United States-Canada Memorandum of Intent on Transboundary Air Pollution, 1983: Final Report.

Venkatram, A., R. E. Ley, and S. Y. Wong, 1982: A statistical model to estimate long-term concentrations of pollutants associated with long-range transport. Atmos. Environ. 16: 249-257.

LIST OF TABLES

TABLE 1

SO_2 EMISSIONS BY STATE AND PROVINCE FOR 1980

STATE	EMISSIONS TONS	% OF U.S. EMISSIONS (40 STATES)	% OF U.S. & CANADIAN EMISSIONS
Alabama (AL)	707,000.5	3.19	2.65
Arizona (AR)	91,998.5	0.41	0.34
Colorado (CO)	122,180.0	0.55	0.46
Connecticut(CT)	65,300.2	0.29	0.24
Deleware(DE)	99,000.3	0.45	0.37
District of Columbia(DC)	13,400.0	0.06	0.05
Florida (FL)	999,020 7	4.50	3.74
Georgia (GA)	752,300.4	3.39	2.82
Illinois (IL)	1336,107.0	6.02	5.01
Indiana (IN)	1818,907.7	8.20	6.82
Iowa (IA)	299,300.0	1.35	1.12
Kansas (KS)	196,400.0	0.89	0.74
Kentucky (KY)	994,799.1	4.49	3.73
Louisiana (LA)	276,200.7	1.25	1.03
Maine(ME)	109,812.7	0.50	0.41
Maryland (MD)	297,078.1	1.34	1.11
Massachusetts (MA)	312,499.9	1.41	1.17
Michigan (MI)	822,606.6	3.71	3.08
Minnesota (MN)	238,800.6	1.08	0.89
Mississippi (MS)	261,200.7	1.18	0.98
Missouri (MO)	1175,887.1	5.30	4.41
Montana (MO)	153,110.0	0.69	0.57
Nebraska (NB)	68,000.0	0.31	0.25
New Hampshire (NH)	84,100.1	0.38	0.32
New Jersey (NJ)	253,300.1	1.14	0.95
New Mexico (NM)	257,210.0	1.16	0.96
New York (NY)	855,633.7	3.86	3.21
North Carolina (NC)	548,399.8	2.47	2.42
North Dakota (ND)	129,110.0	0.58	0.48
Ohio (OH)	2398,209.3	10.81	8.99
Oklahoma (OK)	109,310.9	0.41	
Pennsylvania (PA)	1813,405.8	8.18	6.79
Rhode Island (RI)	13,817.7	0.06	0.05
South Carolina (SC)	301,700.5	1.36	1.13
South Dakota (SD)	35,500.0	0.16	0.13
Tennessee (TN)	976,500.0	4.40	3.66
Texas (TX)	1182,000.0	5.33	4.43
Vermont (VT)	6,100.1	0.03	0.02
Virginia (VA)	302,690.8	1.36	1.13
West Virginia (WV)	989,400.0	4.46	3.71
Wisconsin (WI)	544,101.2	2.45	2.04
Wyoming (WY	168,690.0	0.76	0.63

TABLE 1 (cont'd)

SO_2 EMISSIONS BY STATE AND PROVINCE FOR 1980

PROVINCE	EMISSIONS TONS	PERCENT OF CANADIAN EMISSIONS (40 STATES)	% OF U.S. & CANADIAN EMISSIONS
Alberta (ALTA)	535,000.8	11.87	2.00
Manitoba (MAN)	492,935.0	10.94	1.85
New Brunswick (NB)	249,284.0	5.53	0.93
Newfoundland (NFLD)	67,354.0	1.49	0.25
Nova Scotia (NS)	162,572.0	3.61	0.61
Ontario (ONT)	1794,540.2	39.81	6.72
Prince Edward Island (PEI)	8,724.0	0.19	0.03
Quebec (QUE)	1155,322.5	25.63	4.33
Saskatchewan (SASK)	41,595.0	0.92	0.16

TABLE 2
MAJOR POINT SOURCE AND AREA SOURCE EMISSIONS BY COUNTY
ALL ESTIMATES IN TONS SO_2/YEAR

	SO_2 EMISSIONS 1980			SO_2 EMISSIONS 1990				SO_2 EMISSIONS 1990/CAP[4]			
COUNTY	DIST[1]	MAJ PT[2]	OIL NPT[3]	DIST.	MAJ PT	OIL NPT	COAL	DIST.	MAJ PT	OIL NPT	COAL
ANDROSCOGGIN	869	-----	1672	738	----	1977	204	738	----	1582	204
AROOSTOOK	782	-----	2236	631	----	1864	545	631	----	1491	545
Fraser	----	5456	----	----	912	----	----	----	729	----	----
CUMBERLAND	1886	-----	722	1624	----	2238	449	1624	----	1791	449
CMP 1,2,3	----	-----	----	----	6261	----	----	----	5008	----	----
CMP 4	----	14978	----	----	3506	----	----	----	3506	----	----
S.D. Warren	----	4883	----	----	483	----	2700	----	386	----	2700
FRANKLIN	243	-----	39	214	----	272	59	214	----	218	59
IP Andros	----	11820	----	----	7950	----	----	----	6360	----	----
James River	----	953	----	----	947	----	----	----	757	----	----
HANCOCK	365	-----	58	315	----	402	87	315	----	321	87
St Regis	----	4080	----	----	1109	----	1600	----	887	----	1600
KENNEBEC	965	-----	1333	850	----	1888	235	850	----	1510	235
Scott Win	----	2569	----	----	1745	----	----	----	1396	----	----
Statler	----	1495	----	----	1604	----	----	----	1283	----	----
KNOX	287	-----	1122	256	----	1320	71	256	----	1056	71
Dragon Cement							1980				1980
LINCOLN	226	-----	36	189	----	241	52	189	----	193	52
CMP Mason	----	2638	----	----	119	----	----	----	119	----	----
OXFORD	426	-----	69	340	----	433	94	340	----	346	94
Boise Cascad	----	5566	----	----	7103	----	----	----	5682	----	----

TABLE 2
(cont)

SO_2 EMISSIONS

	1980			1990				1990/CAP			
COUNTY	DIST	MAJ PT	OIL NPT	DIST.	MAJ PT	OIL NPT	COAL	DIST.	MAJ PT	OIL NPT	COAL
PENOBSCOT	1200	-----	998	1062	----	2088	293	1062	----	1671	293
GNP Mill	----	12632	----	----	11925	----	----	----	9540	----	----
GNP E. Mill	----	4103	----	----	2384	----	----	----	1908	----	----
Lincoln	----	3017	----	----	994	----	1400	----	795	----	1400
James River	----	1810	----	----	1967	----	----	----	1574	----	----
Eastern Fine	----	1259	----	----	1457	----	----	----	1165	----	----
Bangor Hyrd	----	1037	----	----	1179	----	----	----	943	----	----
PISCATAQUIS	156	-----	25	127	----	161	35	127	----	129	35
SAGADAHOC	252	-----	1274	177	----	1358	49	177	----	1086	49
SOMERSET	400	----	902	364	----	463	100	364	----	370	100
S.D.Warren	----	1526	----	----	2043	----	----	----	1634	----	----
Madison	----	-----	----	----	1325	----	----	----	1060	----	----
WALDO	243	-----	39	201	----	256	56	201	----	205	56
WASHINGTON	296	-----	48	217	----	276	60	217	----	221	60
Georgia Pac	----	3169	----	----	2444	----	----	----	1955	----	----
YORK	1243	-----	1142	1164	----	2648	321	1164	----	2118	321
Port Navy	----	1769	----	----	1923	----	----	----	1538	----	----
TOTAL	9840	84759	11717	8470	59378	17886	----	8470	48228	14309	----

1. Distillate oil, includes residential, commercial, transportation & industry sectors.
2. Major Point Source, includes point sources with emissions greater than 1,000 tons/yr.
3. Oil NPT - Oil - nonpoint source - includes all residual oil excluding use at major point sources.
4. 1990/CAP - Projected 1990 Emissions after imposition of a 2.0% fuel sulfur limitation.

TABLE 3

POINT AND AREA SOURCE EMISSIONS FOR MAINE (tons)

	1980	1990	1990 WITH SULFUR LIMITATION
MAJOR POINT	88,260	70,560	59,405
AREA	21,554	29,064	25,487
TOTAL	109,814	99,624	84,892

TABLE 4

SO_2 EMISSIONS FOR MAINE BY SOURCE CATEGORY (kilotons)

	1980	1990	1990 WITH SULFUR LIMITATION
DISTILLATE	9,839 (9%)	8,469 (9%)	8,469 (10%)
MAJOR POINT-OIL (61%) (PLUS PROCESS)	88,260 (80%)	62,880 (63%)	51,725
NON-POINT-OIL (17%)	11,715 (11%)	17,885 (18%)	14,308
COAL (12%)	0.0 (0%)	10,390 (10%)	10,390
TOTAL	109,814	99,624	84,892

NOTE: Numbers in parentheses are the percent contributions to the total SO_2 emissions.

TABLE 5

PERCENT CONTRIBUTION OF MAJOR POINT AND AREA SOURCES
TO SULFUR DEPOSITION FROM MAINE FOR 1980

RECEPTOR	MAJOR POINT SOURCES	AREA SOURCES
#1 ACADIA	76	24
#2 BRIDGTON	74	26
#3 CARIBOU	66	34
#4 GREENVILLE	65	35
#5 MT. KATAHDIN	83	17
#7 GRAND MANAN IS.	81	19
#10 FROG LAKE	86	14

TABLE 6

PERCENT CONTRIBUTION OF FOUR SOURCE CATEGORIES
TO SULFUR DEPOSITION FROM MAINE FOR 1980

RECEPTOR	DISTILLATE SOURCES	MAJOR POINT (OIL & PROCESS) SOURCES	NON-POINT OIL SOURCES	COAL SOURCES
#1 ACADIA	11	76	13	0
#2 BRIDGTON	13	74	13	0
#3 CARIBOU	11	64	25	0
#4 GREENVILLE	12	66	22	0
#5 MT. KATAHDIN	8	83	9	0
#7 GRAND MANAN IS.	10	80	10	0
#10 FROG LAKE	7	86	7	0

TABLE 7

PERCENT CONTRIBUTION OF NESCAUM STATES' EMISSIONS
TO TOTAL SULFUR DEPOSITION FOR 1980

RECEPTOR	ME	NH	VT	MA	CT	RI	NY	NJ
#1 ACADIA	7.0	2.4	0.2	3.9	0.6	0.2	9.1	1.3
#2 BRIDGTON	2.8	2.5	0.4	3.2	0.5	0.1	11.6	1.2
#3 CARIBOU	3.8	0.7	0.1	1.5	0.3	0.1	5.1	0.8
#4 GREENVILLE	4.4	1.0	0.2	1.8	0.3	0.1	6.6	0.8
#5 MT. KATAHDIN	4.7	0.9	0.1	1.7	0.3	0.1	6.0	0.8
#7 GRAND MANAN IS.	5.9	1.9	0.2	3.8	0.5	0.1	8.1	1.3
#10 FROG LAKE	7.2	1.1	0.1	2.3	0.4	0.1	6.2	0.9

TABLE 8

PERCENT CONTRIBUTIONS TO MAINE'S SULFATE DEPOSITION

SOURCE	FAY/FOSENZWEIG	MOE
ME	2	3-7
NH	1	1-3
VT	0	¼1
MA	3	2-4
RI	0	¼1
CT	1	¼1
NY	11	5-12
NJ	2	1
PA	15	5-9
DE	1	¼1
MD	2	¼1
VA	2	¼1
WV	6	2-3
NC	1	¼1
OH	17	6-9
IN	6	3-4
IL	6	2-3
MI	7	3-5
WI	2	2
KY	5	1-2
TN	3	1

TABLE 9

TOTAL SULFATE DEPOSITION FROM MAINE SOURCES (kg/ha)

RECEPTOR	1980	1990	1990 w S LIMITATION
#1	2.169	2.148 (1)	1.827 (16)
#2	.999	.981 (3)	.843 (16)
#3	.816	.672 (18)	.573 (30)
#4	1.368	1.182 (14)	1.011 (26)
#5	1.296	1.206 (7)	1.023 (21)
#6	1.224	1.107 (10)	.098 (23)
#7	1.656	1.602 (3)	1.356 (18)
#8	.768	.468 (39)	.396 (48)
#9	.762	.663 (13)	.561 (26)
#10	1.866	1.71 (8)	1.449 (22)
#11	.393	.345 (12)	.294 (25)
#12	.408	.366 (10)	.312 (24)
#13	.612	.558 (9)	.474 (23)
#14	.822	.75 (9)	.636 (23)
#15	.984	.921 (6)	.78 (21)
#16	1.116	1.059 (5)	.091 (19)
#17	.3969	.03025 (13)	1.417 (25)
#18	.084	.072 (14)	.6 (29)
#19	.168	.144 (14)	.123 (27)

NOTE: The numbers in parentheses represent the percent reduction in deposition from Maine sources over that predicted for 1980.

TABLE 10

PERCENT CONTRIBUTION OF MAINE SOURCES
TO TOTAL SULFUR DEPOSITION

RECEPTOR	1980	1990	1990 w S LIMITATION
#1	6.99	6.92	5.96
#2 Bridgton	2.81	2.74	2.36
#3	3.76	3.11	2.67
#4	4.37	3.80	3.27
#5	4.68	4.37	3.73
#6	4.94	4.50	3.84
#7	5.93	5.75	4.91
#8	3.87	2.40	2.03
#9	3.52	3.06	2.61
#10	7.16	6.60	5.65
#11	2.41	2.13	1.82
#12	2.15	1.93	1.65
#13	2.73	2.49	2.12
#14	3.47	3.18	2.71
#15	3.87	3.63	3.09
#16	4.20	3.99	3.43
#17	0.91	0.79	0.68
#18	1.13	0.96	0.81
#19	1.78	1.55	1.32

TABLE 11

PERCENT REDUCTION IN TOTAL SULFUR DEPOSITION
RESULTING FROM REDUCTIONS IN MAINE EMISSIONS

RECEPTOR	1990	1990 w S LIMITATION
#1 ACADIA	0.1	1.1
#2 BRIDGTON	0.1	0.5
#3 CARIBOU	0.7	1.1
#4 GREENVILLE	0.6	1.1
#5 MT. KATAHDIN	0.3	1.0
#7 GRAND MANAN IS.	0.2	1.1
#10 FROG LAKE	0.6	1.6

TABLE 12

PERCENT CONTRIBUTION OF MAJOR POINT AND AREA SOURCES TO SULFUR DEPOSITION FROM MAINE FOR 1990

RECEPTOR	MAJOR POINT SOURCES	AREA SOURCES
#1 ACADIA	67	33
#2 BRIDGTON	62	38
#3 CARIBOU	52	48
#4 GREENVILLE	63	37
#5 MT. KATAHDIN	76	24
#7 GRAND MANAN IS.	77	23
#10 FROG LAKE	80	20

TABLE 13

PERCENT CONTRIBUTION OF FOUR SOURCE CATEGORIES
TO SULFUR DEPOSITION FROM MAINE FOR 1990

RECEPTOR	DISTILLATE		MAJOR POINT (OIL & PROCESS)		NON-POINT OIL		COAL	
	1990	1990*	1990	1990*	1990	1990*	1990	1990*
#1 ACADIA	9	11	57	54	21	20	13	15
#2 BRIDGTON	12	14	54	52	23	21	11	13
#3 CARIBOU	12	13	48	47	29	27	11	13
#4 GREENVILLE	13	15	59	56	20	19	8	10
#5 MT. KATAHDIN	8	9	72	70	14	13	6	8
#7 GRAND MANAN IS.	9	10	64	62	17	16	10	12
#10 FROG LAKE	6	7	74	72	12	12	8	9

NOTE: The 1990 scenario assuming a 2.0% sulfur limitation is indicated by "1990*".

TABLE 14

PRECIPITATION-ADJUSTED AVERAGE
ANNUAL SULFATE DEPOSITION (kg/ha)

	1981	1982	1983	1984	AVERAGE
ACADIA	24	26	13	15	18
BRIDGTON	--	27	13	17	18
CARIBOU	--	12	13	--	13
GREENVILLE	--	17	11	--	13

TABLE 15

ANNUAL WET SULFATE DEPOSITION (kg/ha)

	1981	1982	1983	1984
ACADIA	24 (27)	23 (24)	21 (26)	17 (22)
BRIDGTON	----	20 (21)	18 (18)	18 (20)
CARIBOU	----	12	19	----
GREENVILLE	----	12	16	----
FROG LAKE	----	----	25 (27)	----
GRAND MANAN IS.	----	22 (50)	17 (41)	----

NOTE: The numbers in parentheses indicate total sulfate deposition, without a correction for marine aerosols.

TABLE 16

MEASURED PRECIPITATION AT ACIDIC DEPOSITION SITES (in)

ACADIA	1981	48.94	(50)
	1982	43.83	(51)
	1983	75.76	(51)
	1984	55.23	(50)
BRIDGTON	1982	27.61	(44)
	1983	52.84	(44)
	1984	40.87	(45)
CARIBOU	1982	33.42	(49)
	1983	46.15	(47)
GREENVILLE	1982	28.57	(48)
	1983	55.94	(45)

NOTE: The numbers in parentheses indicate the number of weeks that precipitation data were available.

TABLE 17

30-YEAR AVERAGE PRECIPITATION (in)

	30-YR MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION
BAR HARBOR (1945-1974)	48.93	8.31	0.170
BRIDGTON (1945-1974)	44.67	7.92	0.177
CARIBOU (1938-1968)	35.46	5.26	0.148
GREENVILLE (1945-1974)	44.19	7.18	0.163

TABLE 18

ANALYSIS OF NEEDED DEPOSITION REDUCTIONS

	ACADIA	BRIDGTON
MEASURED SULFATE DEPOSITION (kg/ha/yr) 30-YR AVG PRECIPITATION-ADJUSTED	18.0	17.9
REDUCTION (%) NEEDED TO REACH TARGET OF 16(14) kg/ha/yr	11.1 (22.2)	10.6 (21.8)
MAINE'S CONTRIBUTION (%) TO TOTAL (wet & dry) DEPOSITION (MODELED)	8.0	2.8
MAINE'S PORTION (%) OF REDUCTION NEEDED TO MEET 16(14) kg/ha/yr	0.9 (1.8)	0.3 (0.6)
REDUCTION IN DEPOSITION (%) RESULTING FROM REDUCTION IN MAINE'S SO_2 EMISSIONS 1990 W NO ADDITIONAL CONTROLS	0.08	0.08
REDUCTION IN DEPOSITION (%) RESULTING FROM REDUCTION IN MAINE'S SO_2 EMISSIONS 1990 W 2.0% SULFUR LIMITATION	1.11	0.46

LIST OF FIGURES

FIGURE 1

LOCATIONS OF LARGEST POINT SOURCES OF SO2 IN MAINE

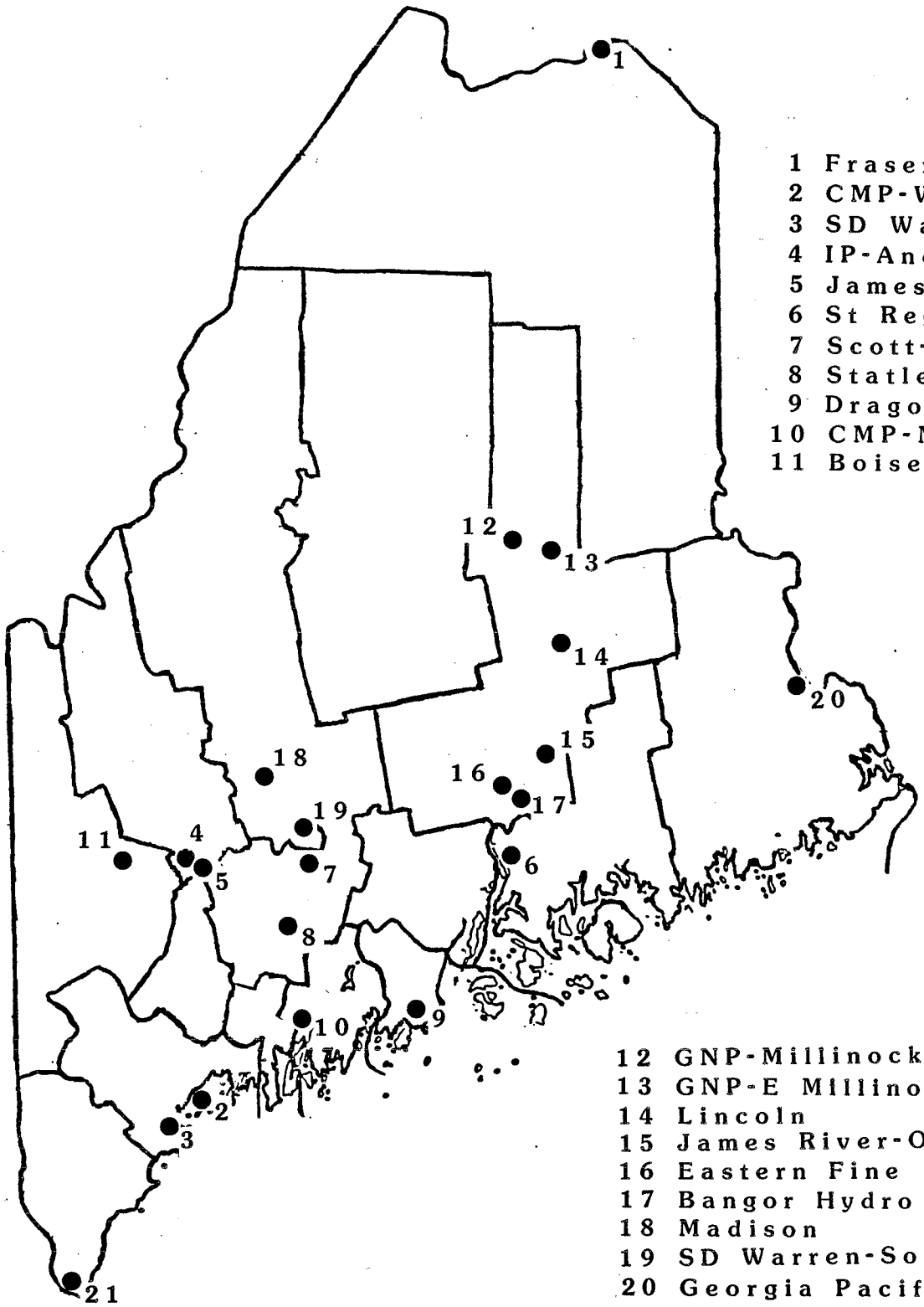
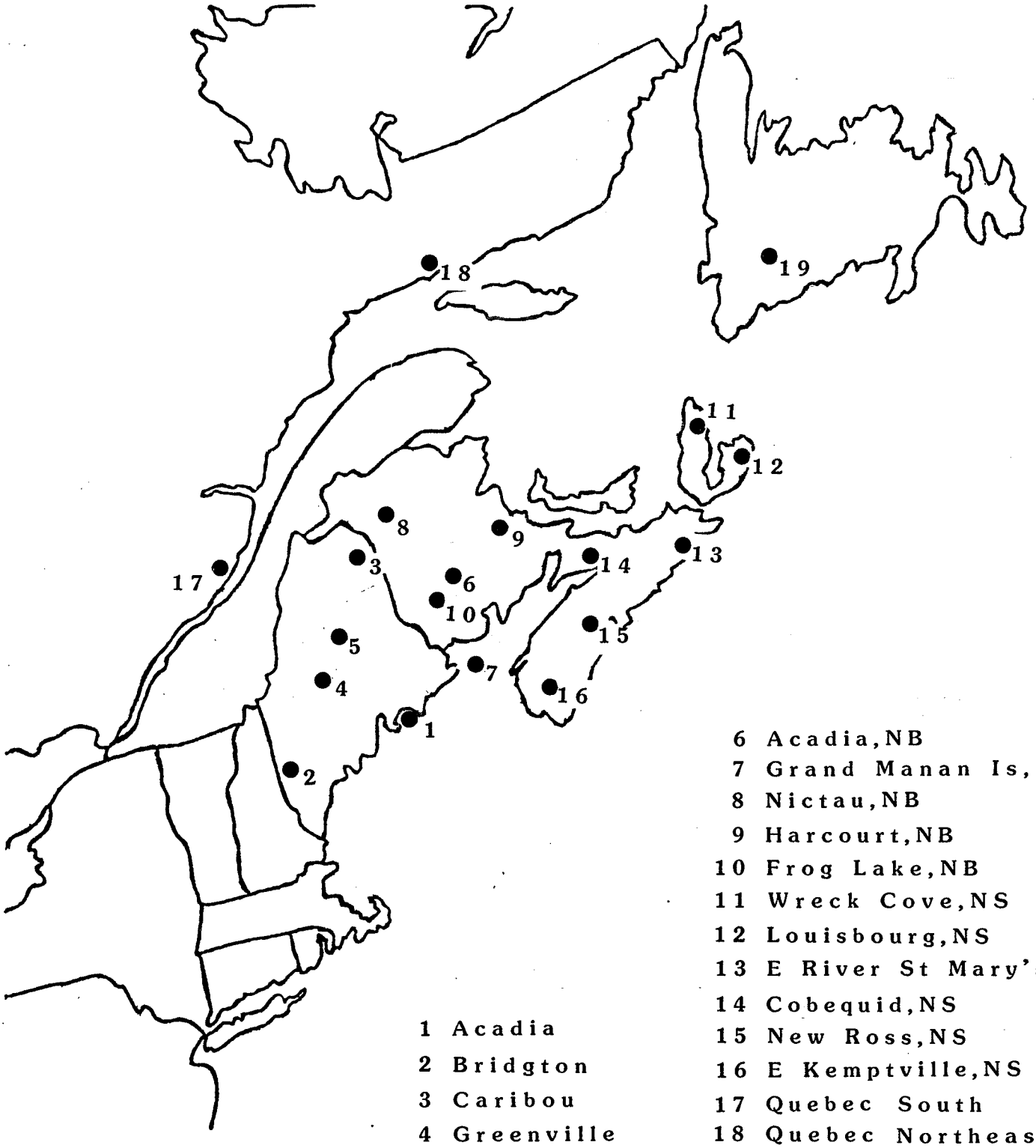


FIGURE 2

RECEPTOR LOCATIONS FOR MOE MODELING



1 Acadia
2 Bridgton
3 Caribou
4 Greenville
5 Mt Katahdin
6 Acadia,NB
7 Grand Manan Is,NB
8 Nictau,NB
9 Harcourt,NB
10 Frog Lake,NB
11 Wreck Cove,NS
12 Louisbourg,NS
13 E River St Mary's,NS
14 Cobequid,NS
15 New Ross,NS
16 E Kemptville,NS
17 Quebec South
18 Quebec Northeast
19 Red Indian Lake,NFLD

FIGURE 3

LOCATIONS OF MAINE NADP MONITORING STATIONS

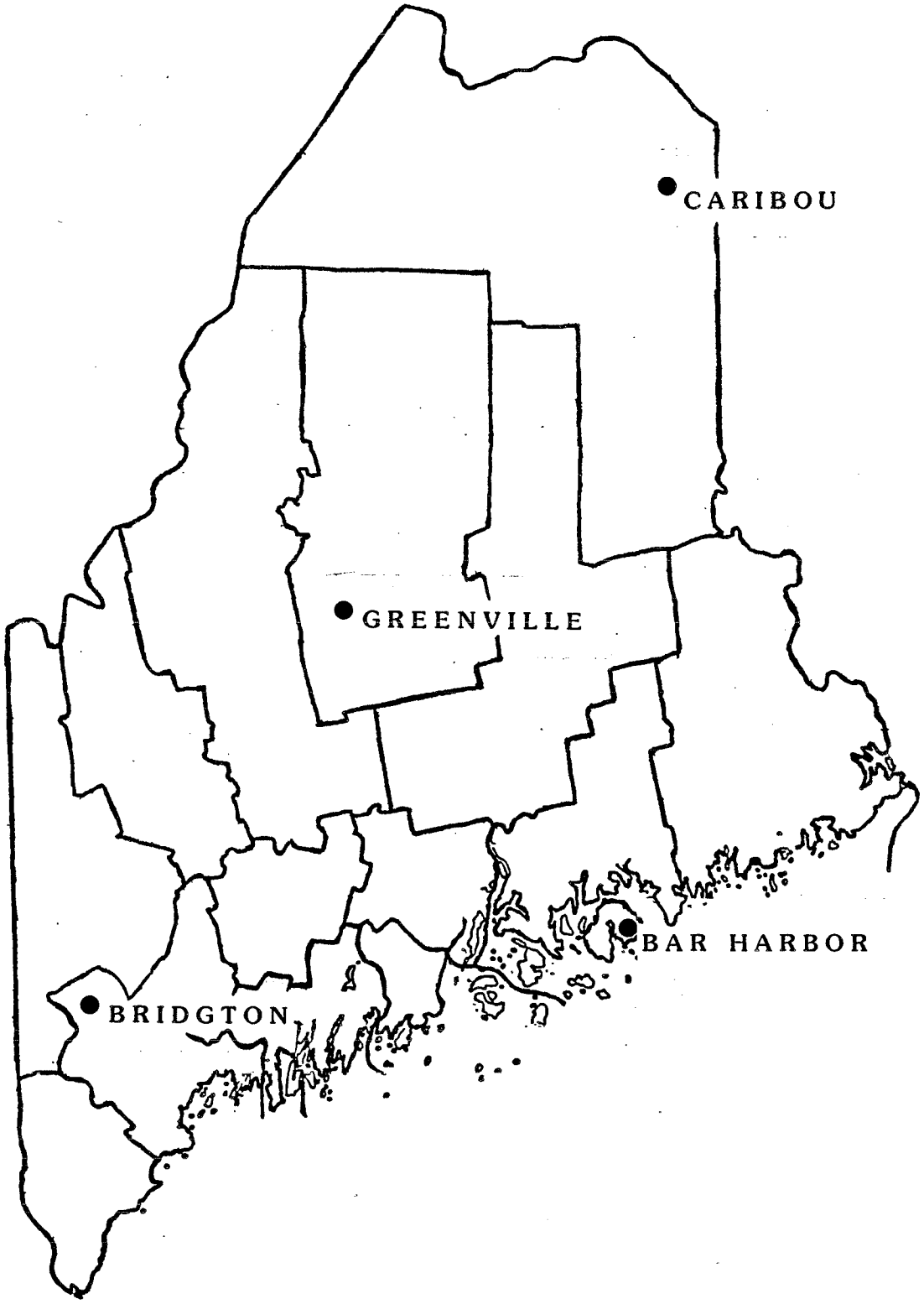


FIGURE 4

MOE MODEL RESULTS - 1980

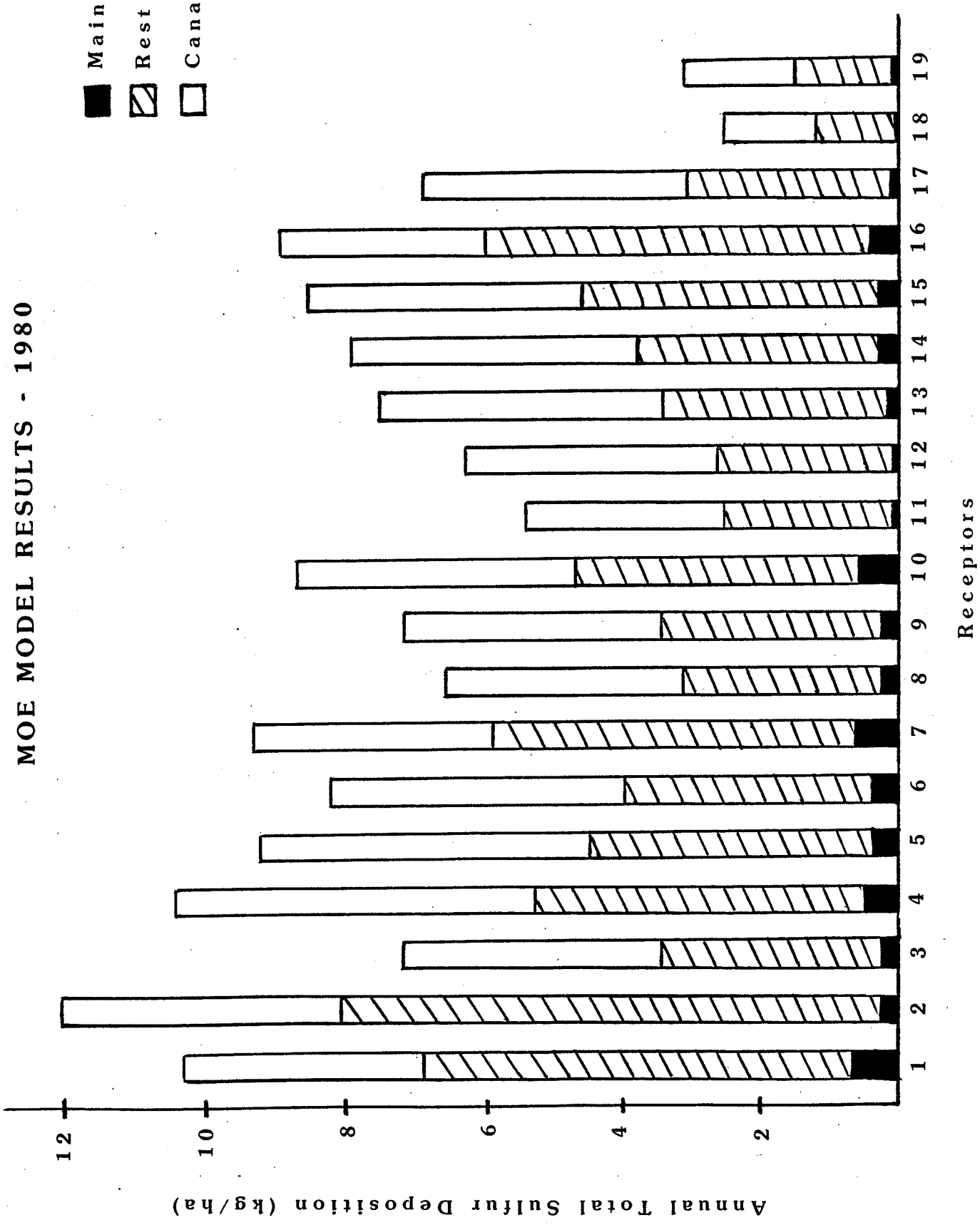


FIGURE 5

MOE MODEL RESULTS - 1980

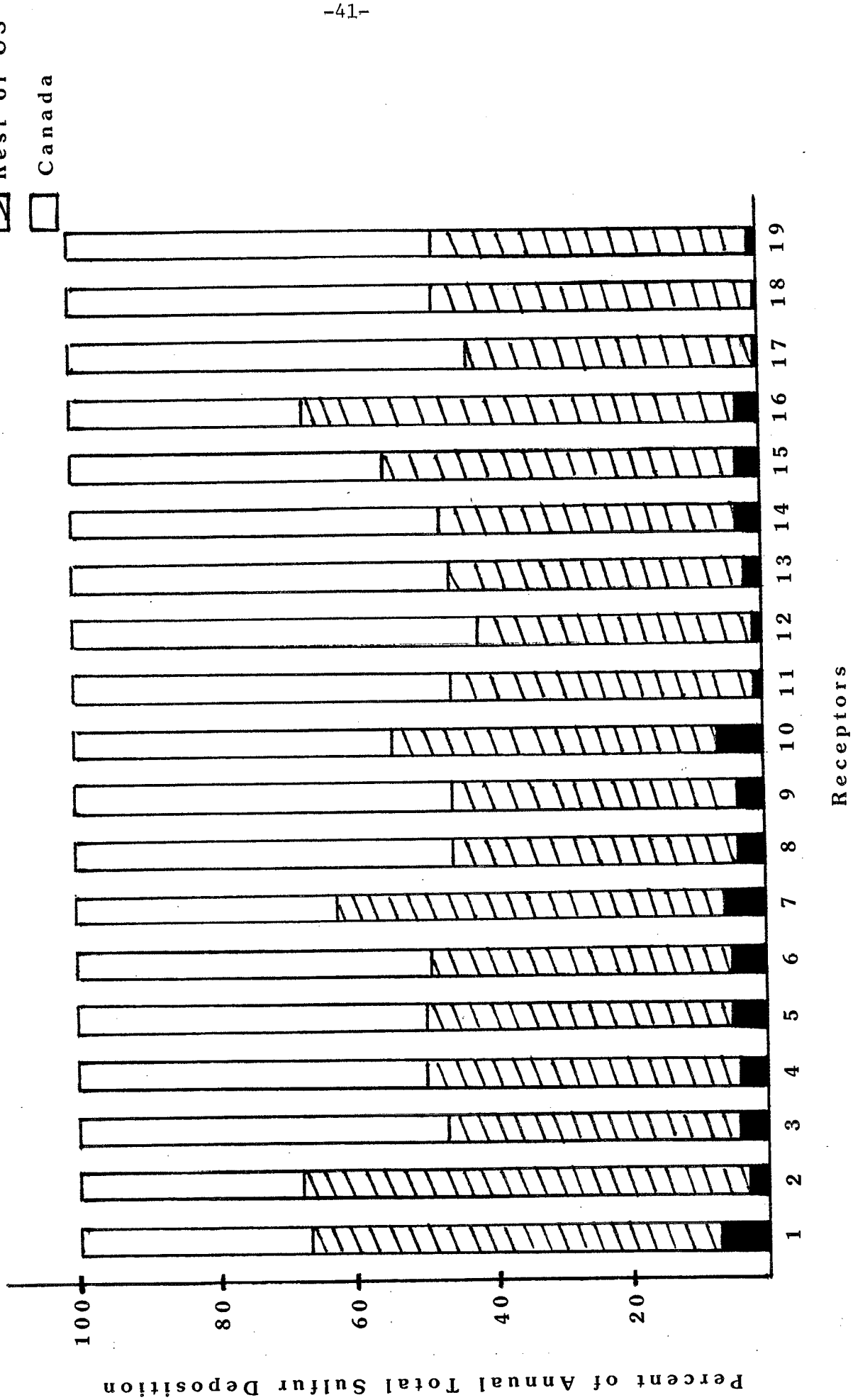


FIGURE 6

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R1-ACADIA,ME

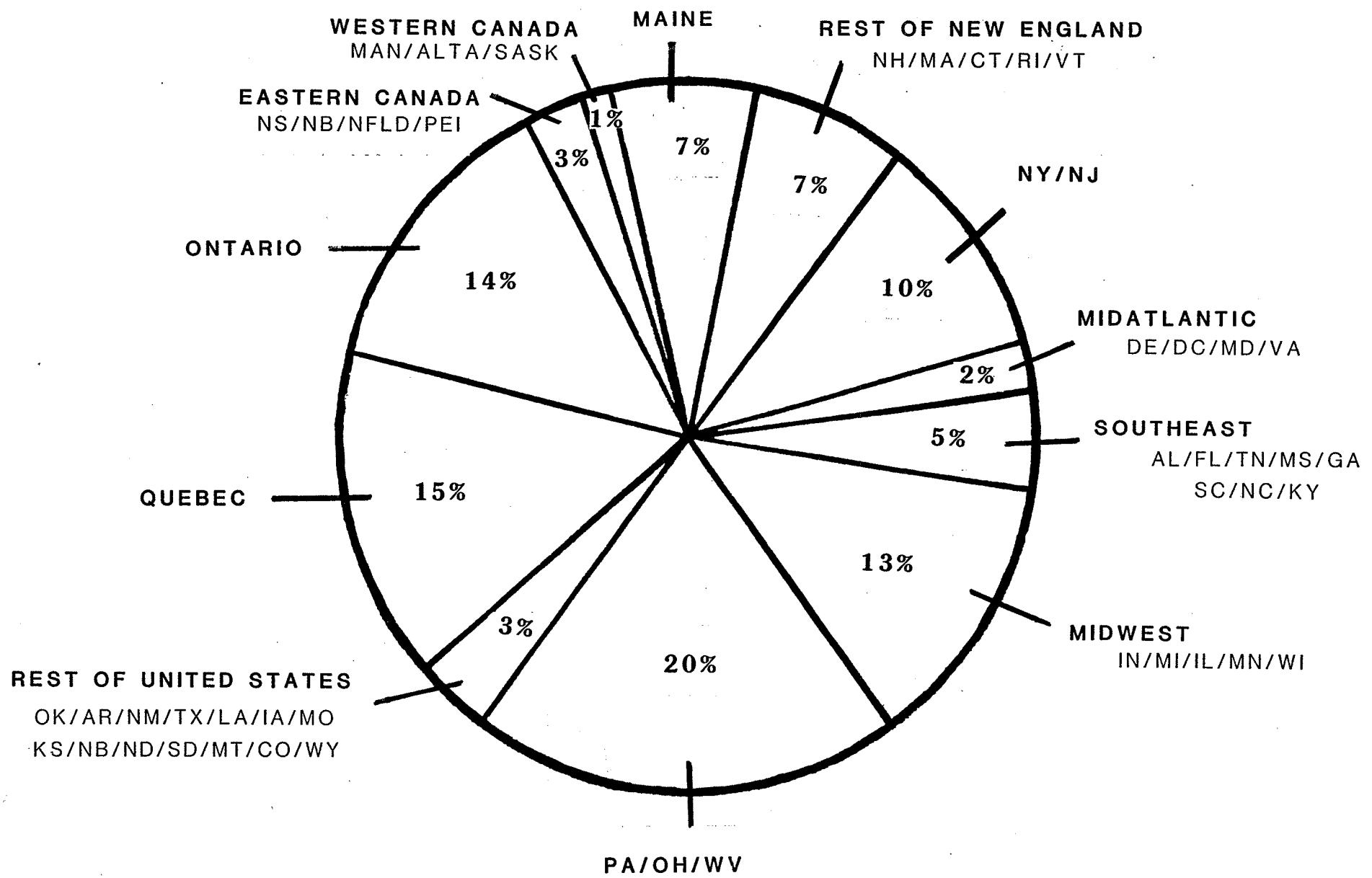


FIGURE 7

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R2-BRIDGTON,ME

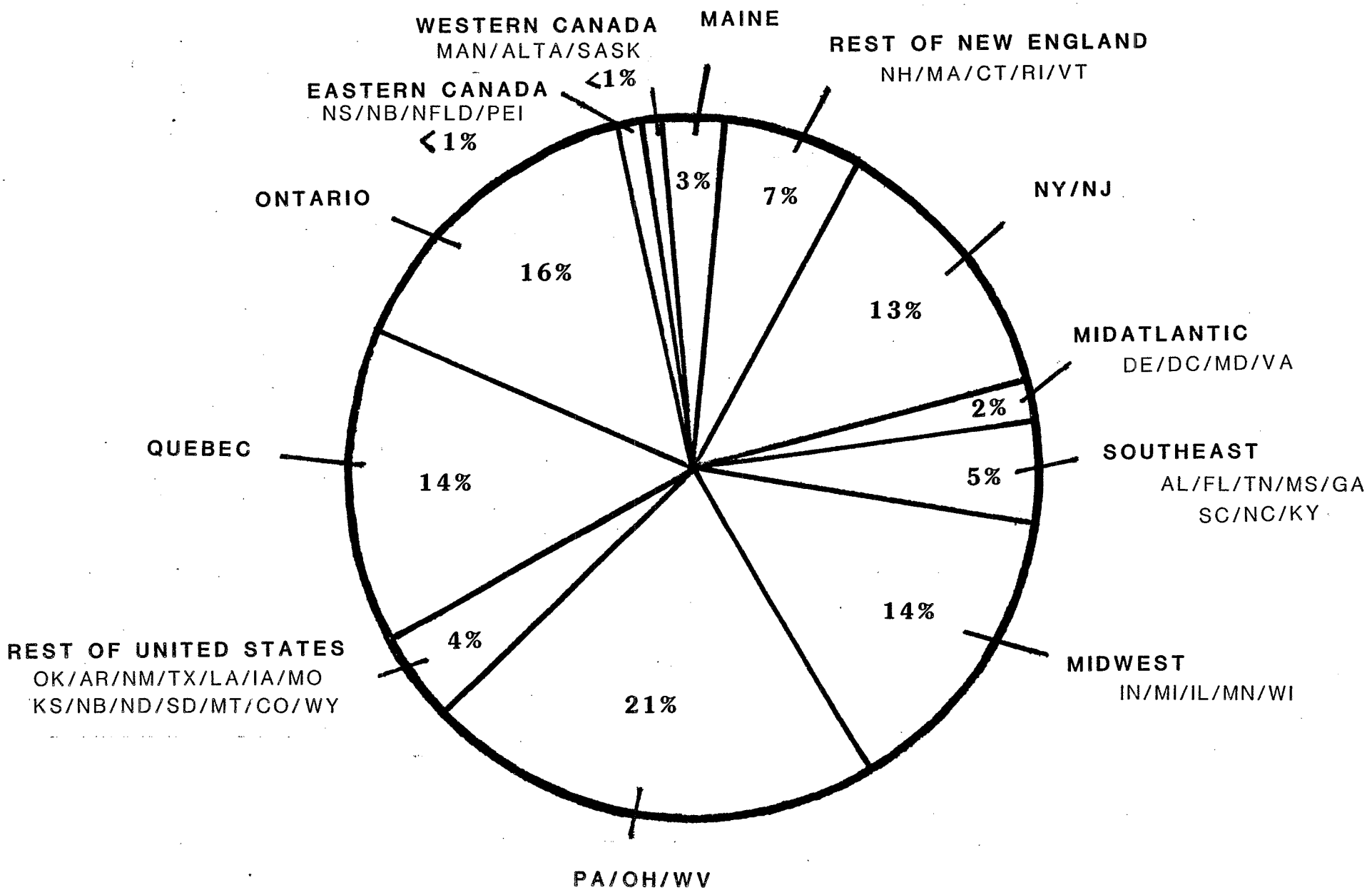


FIGURE 8

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R3-CARIBOU,ME

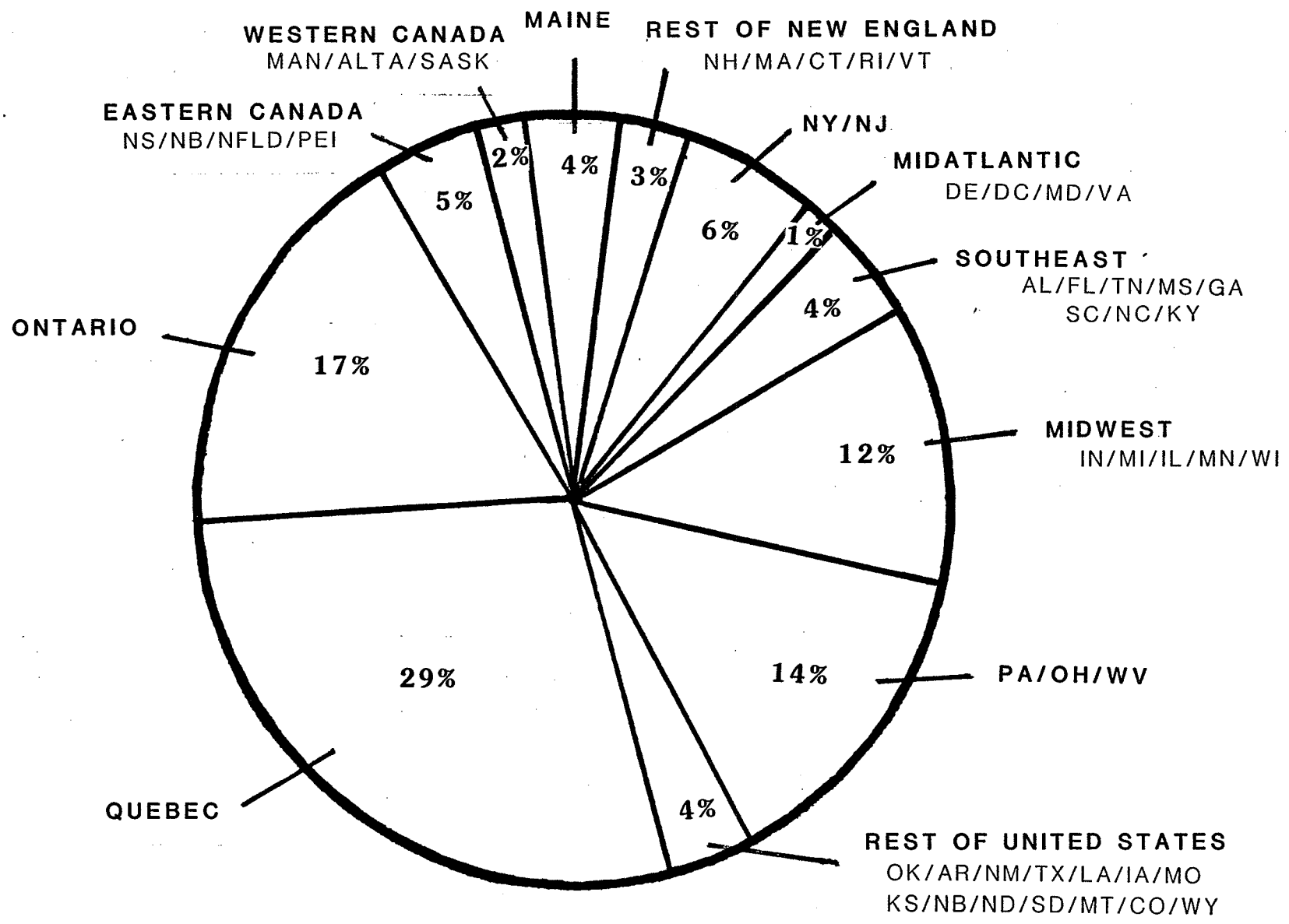


FIGURE 9

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R4-GREENVILLE,ME

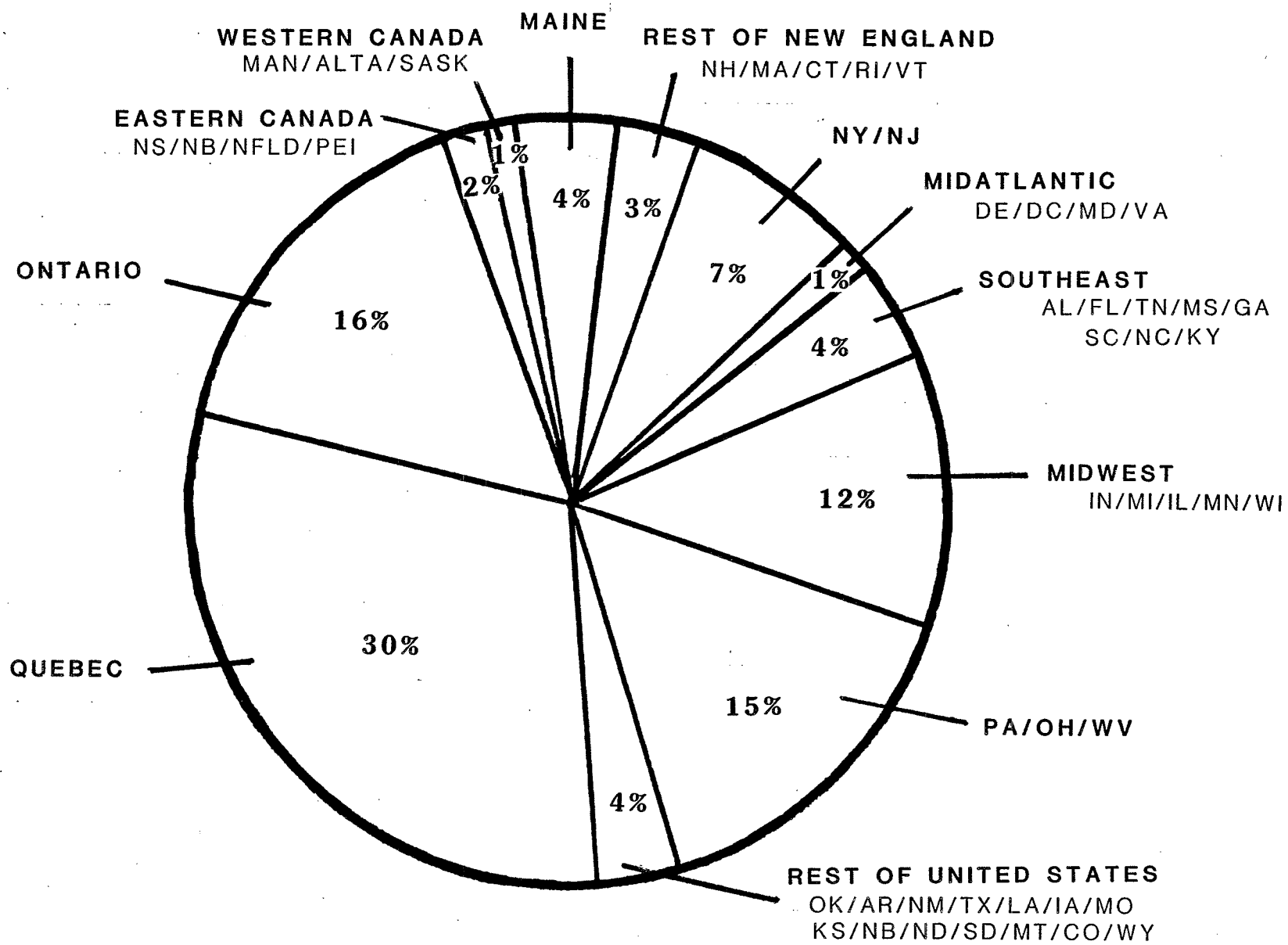


FIGURE 10

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R5-MT KATAHDIN,ME

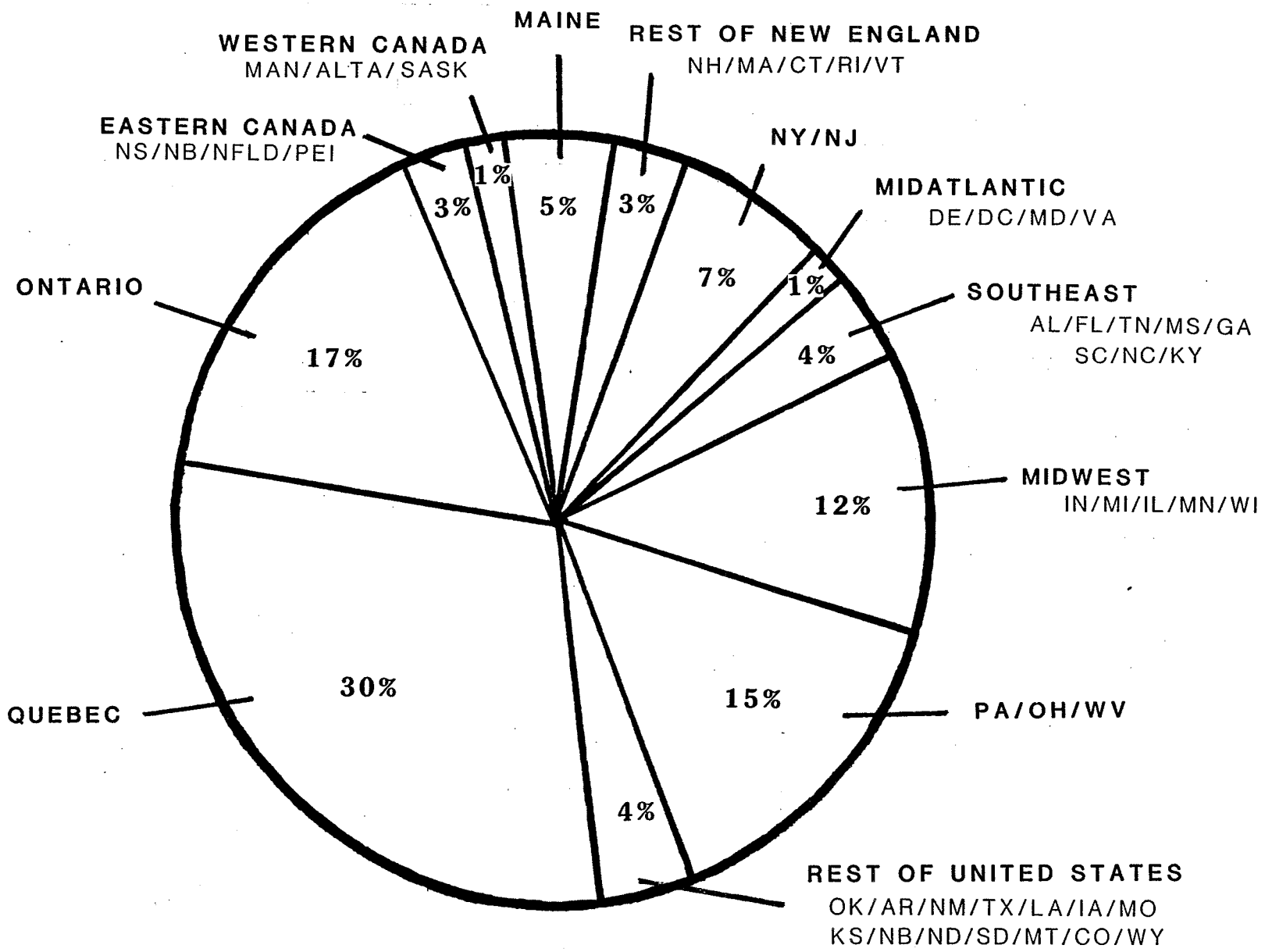


FIGURE 11

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R6-ACADIA,NB

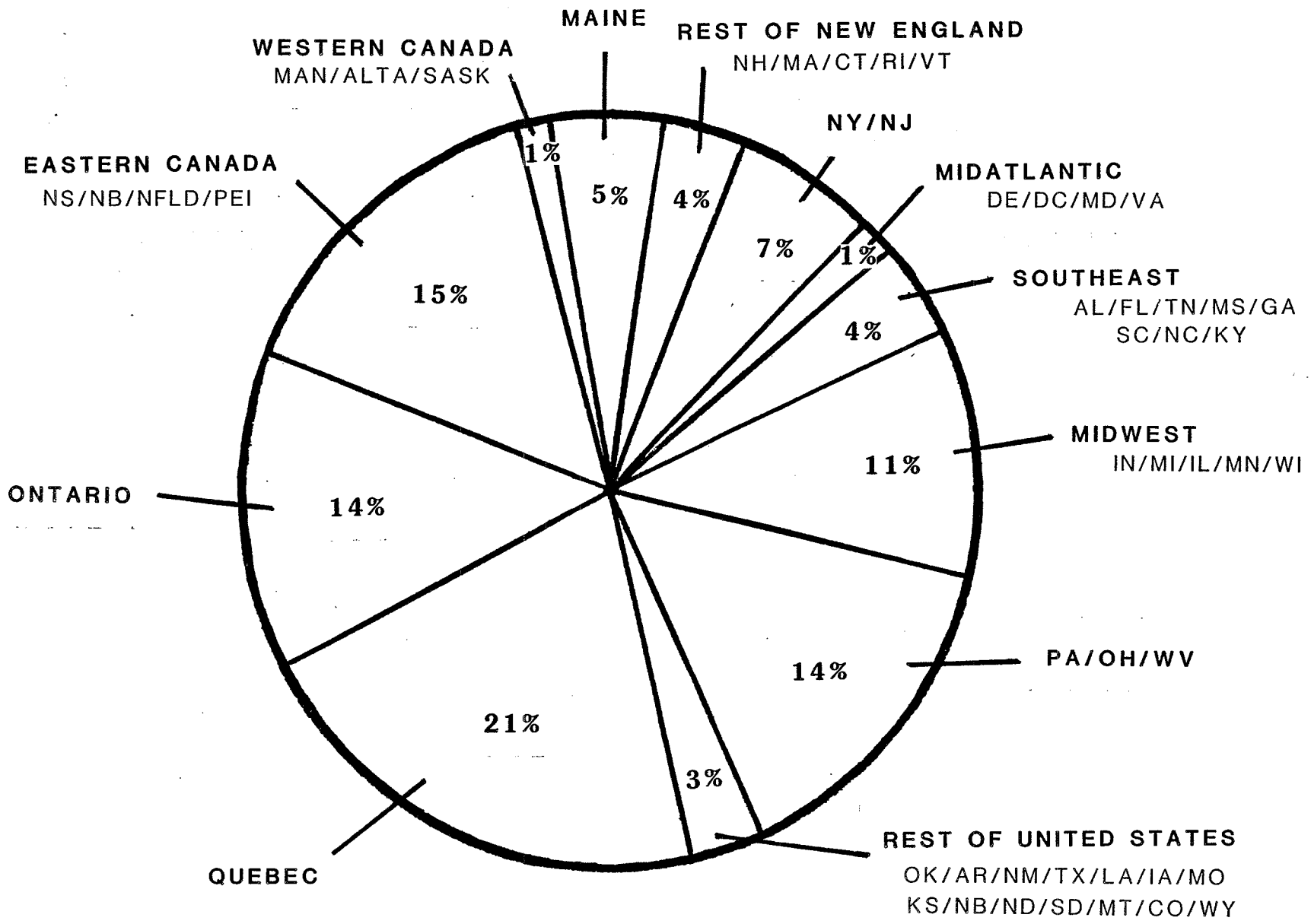


FIGURE 12

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R7-GRAND MANAN IS,NB

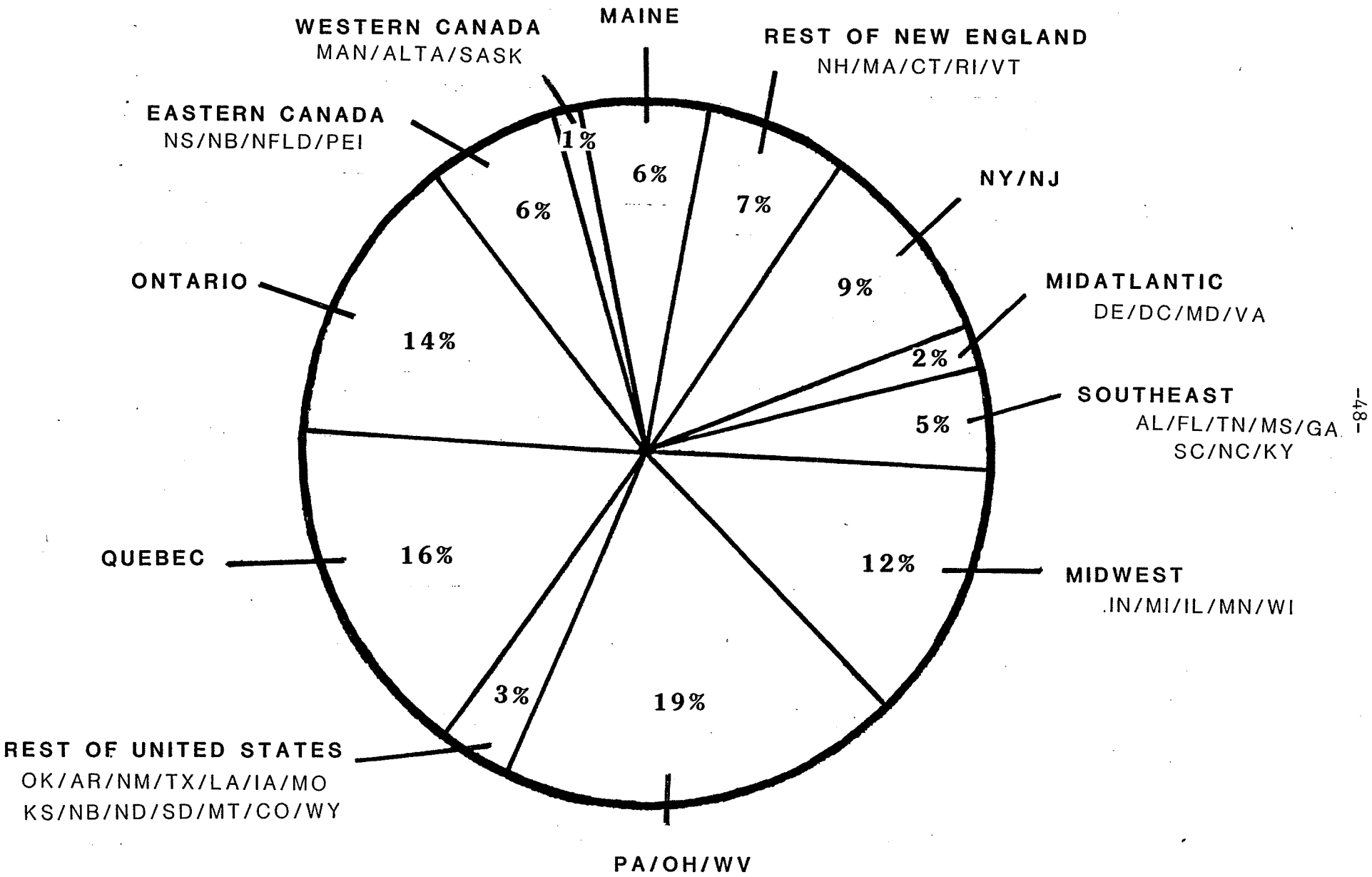


FIGURE 13

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R8-NICTAU,NB

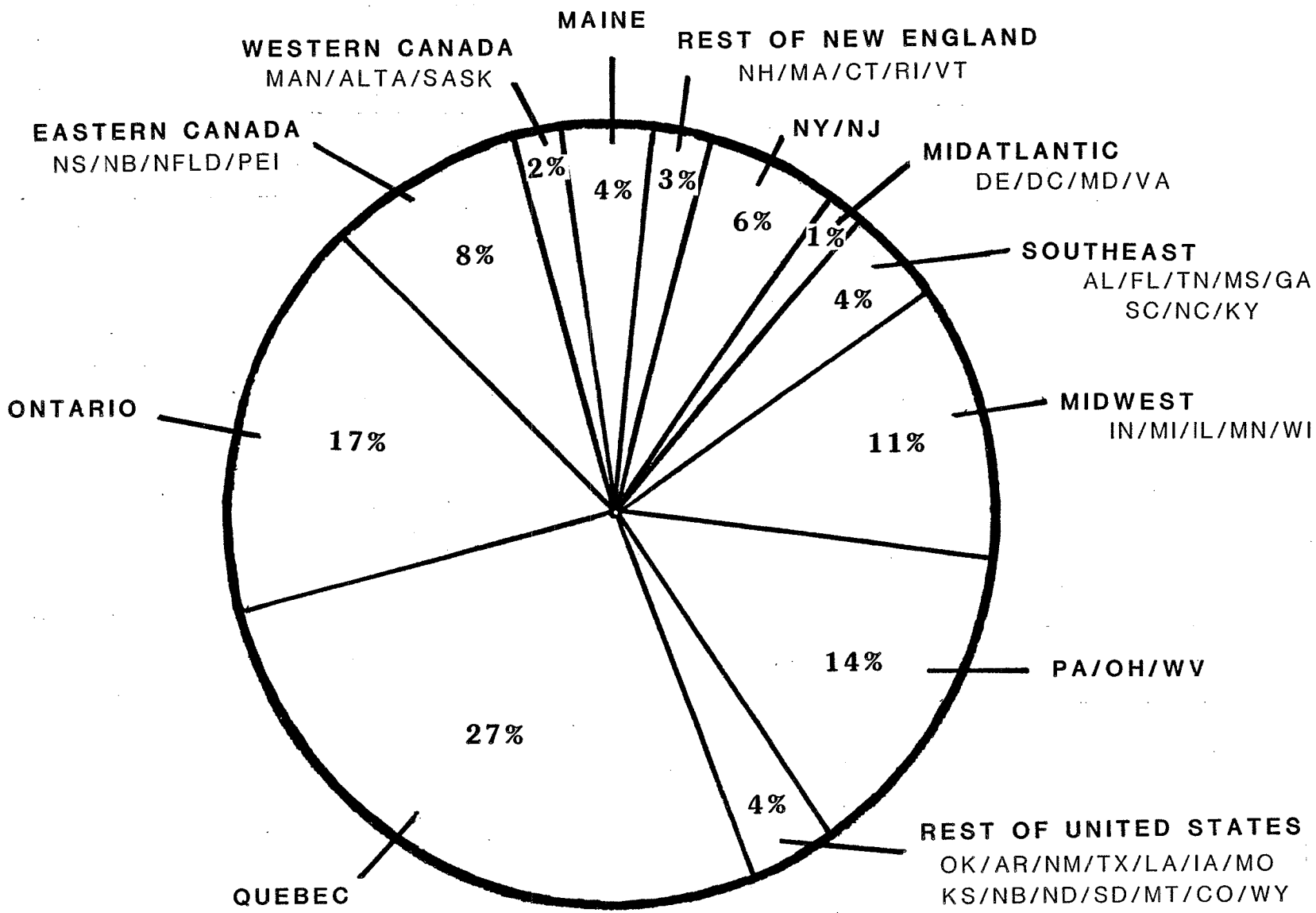


FIGURE 14

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R9-HARCOURT,NB

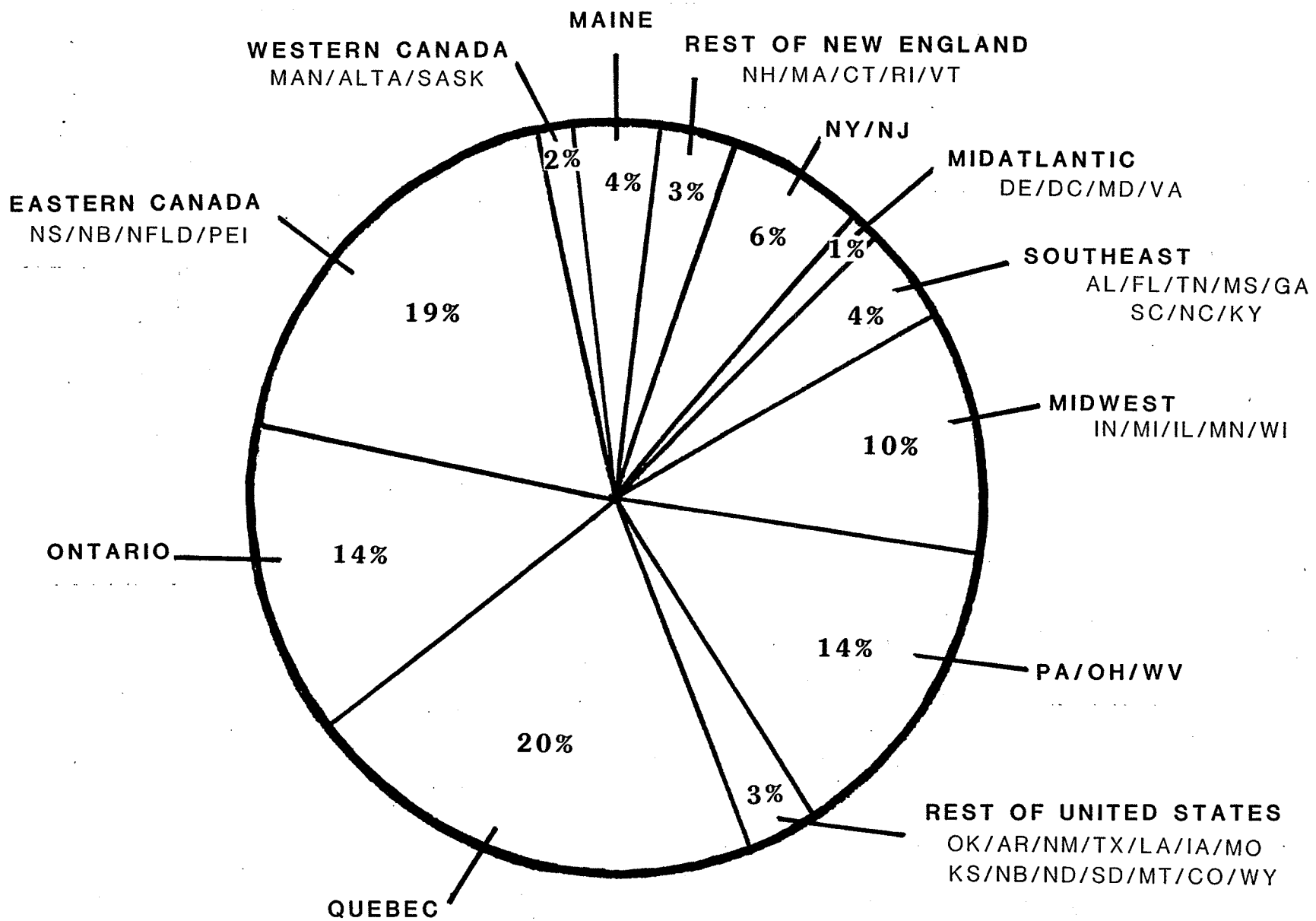


FIGURE 15

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R10-FROG LAKE,NB

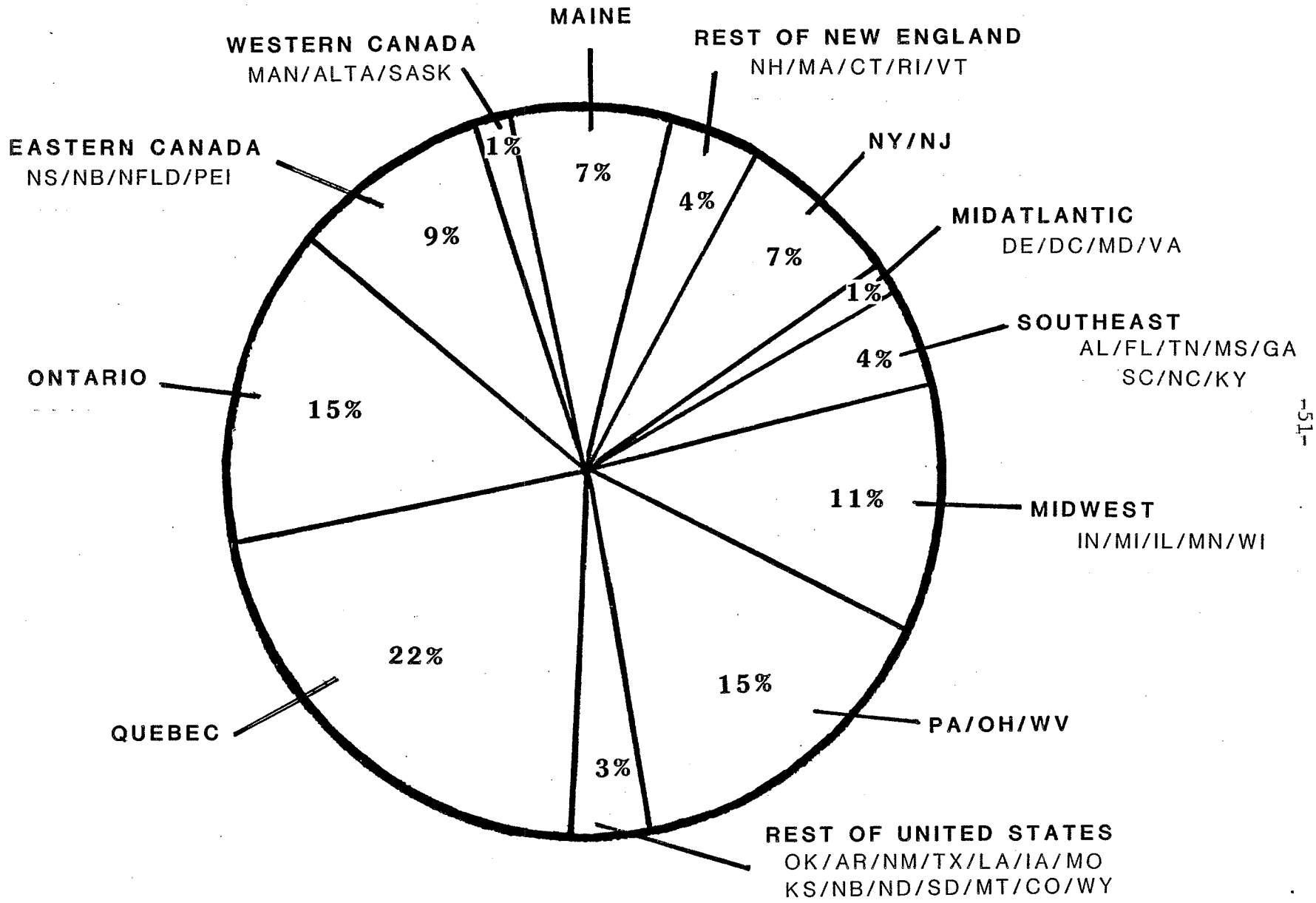


FIGURE 16

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R11-WRECK COVE,NS

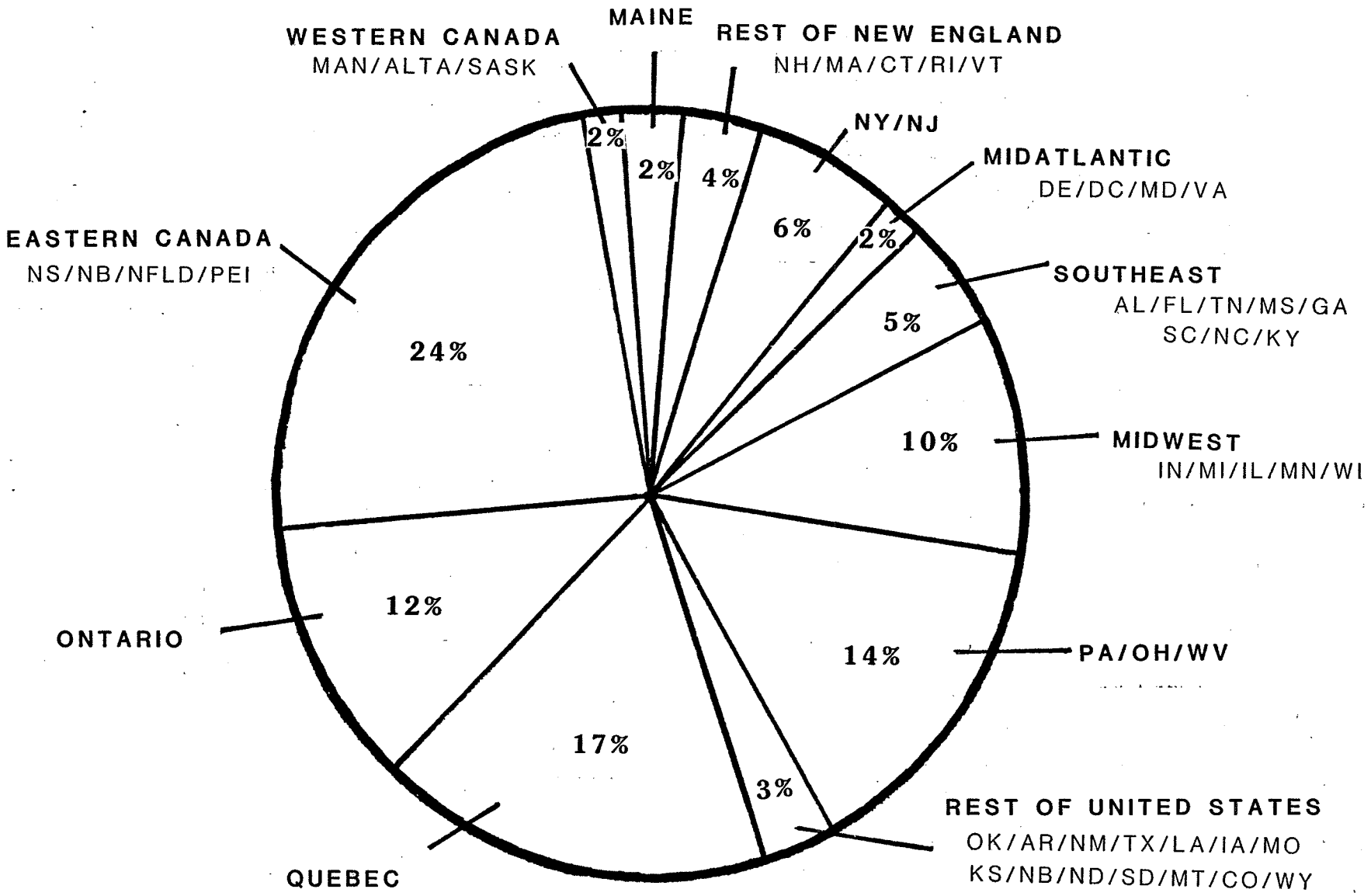


FIGURE 17

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R12-LOUISBOURG,NS

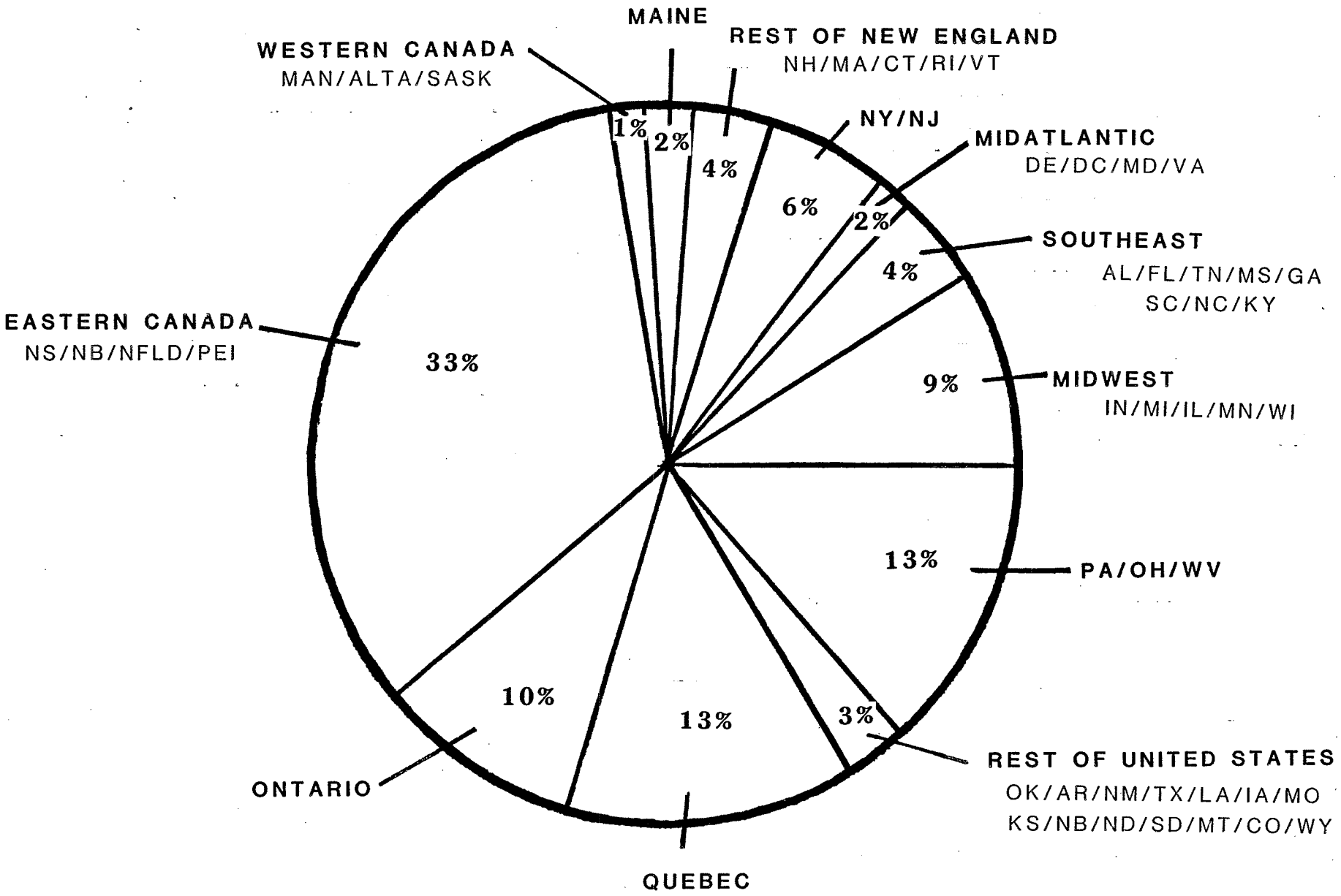


FIGURE 18

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R13-E RIVER ST MARY'S,NS

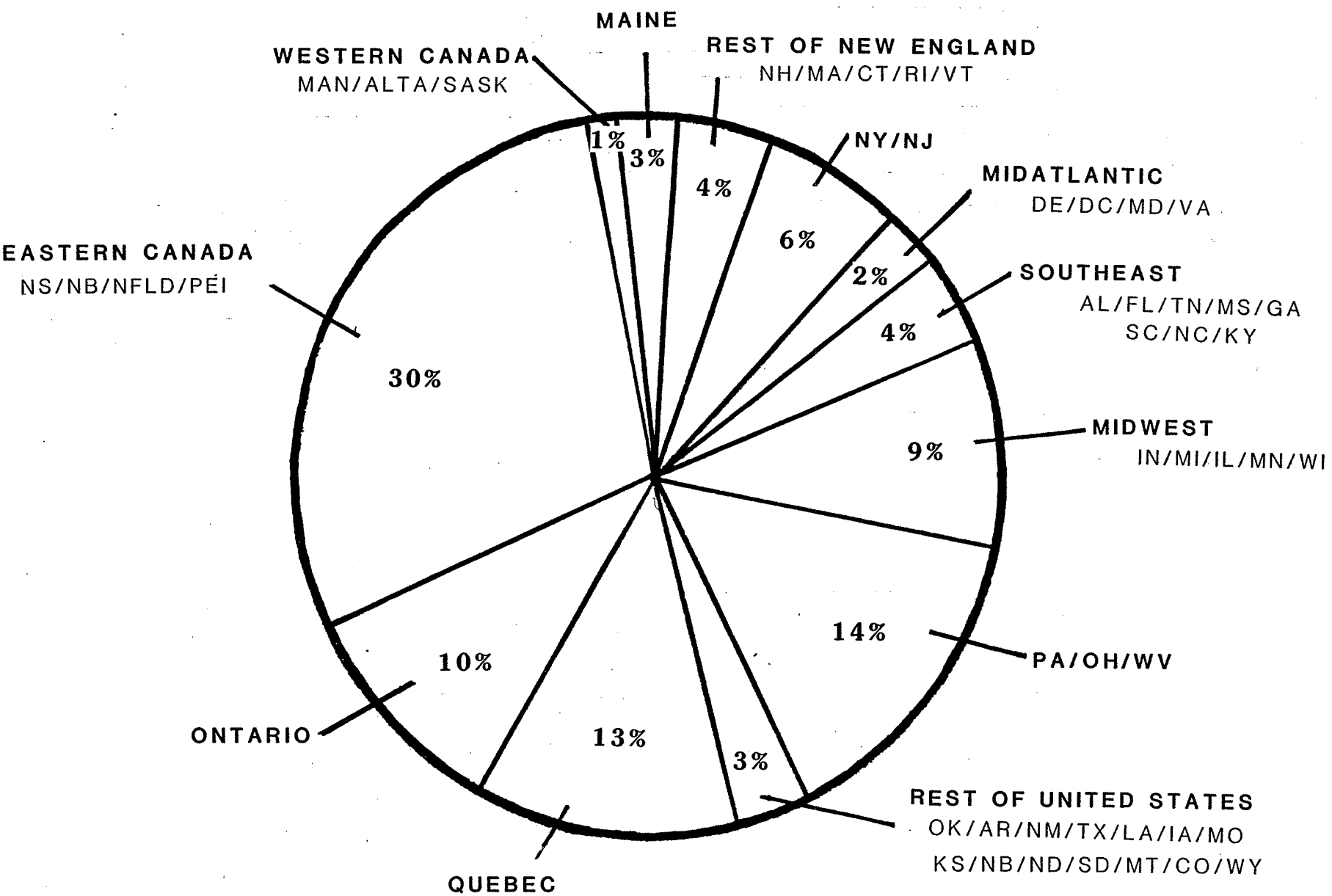


FIGURE 19

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R14-COBEQUID,NS

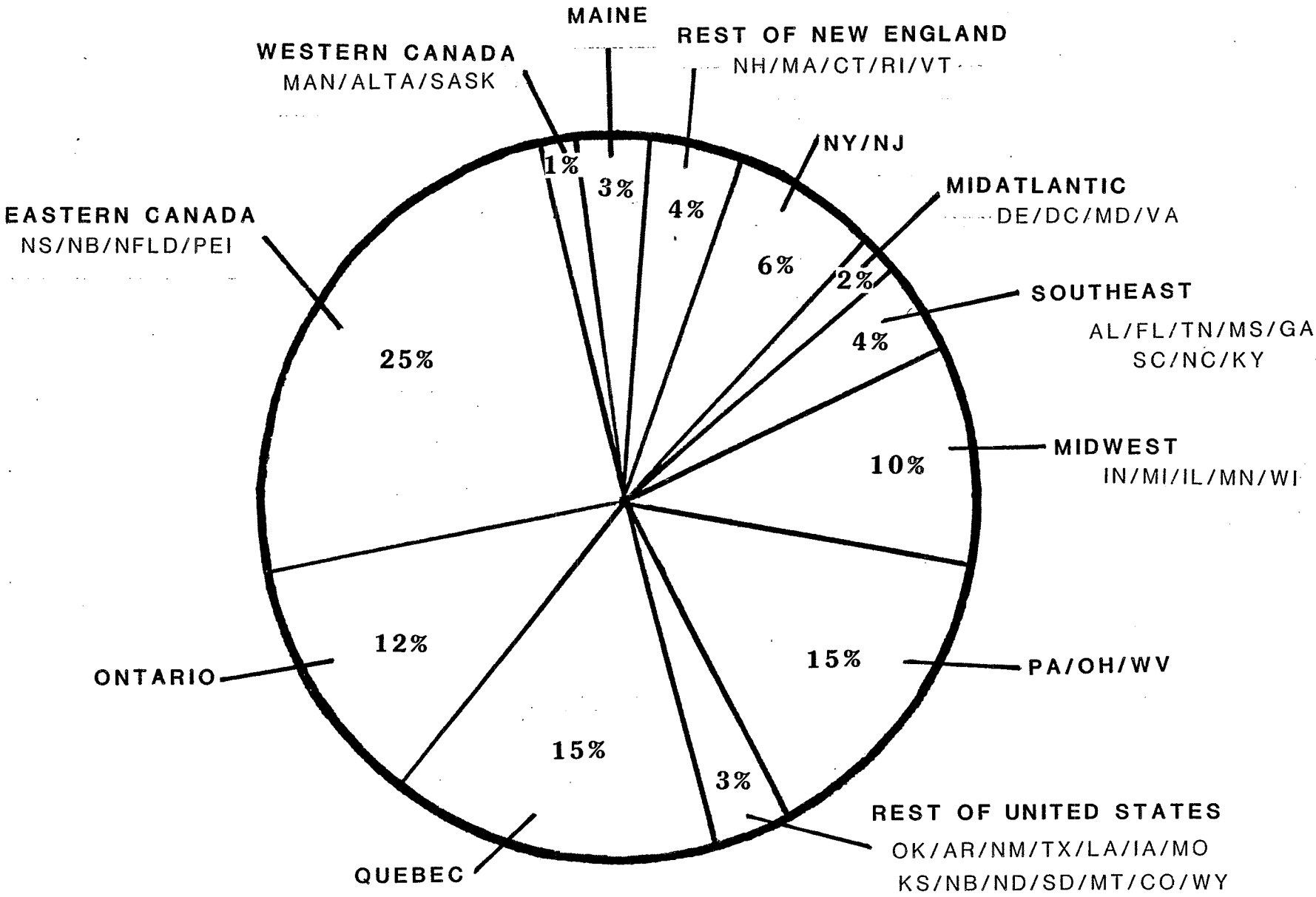


FIGURE 20

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R15-NEW ROSS,NS

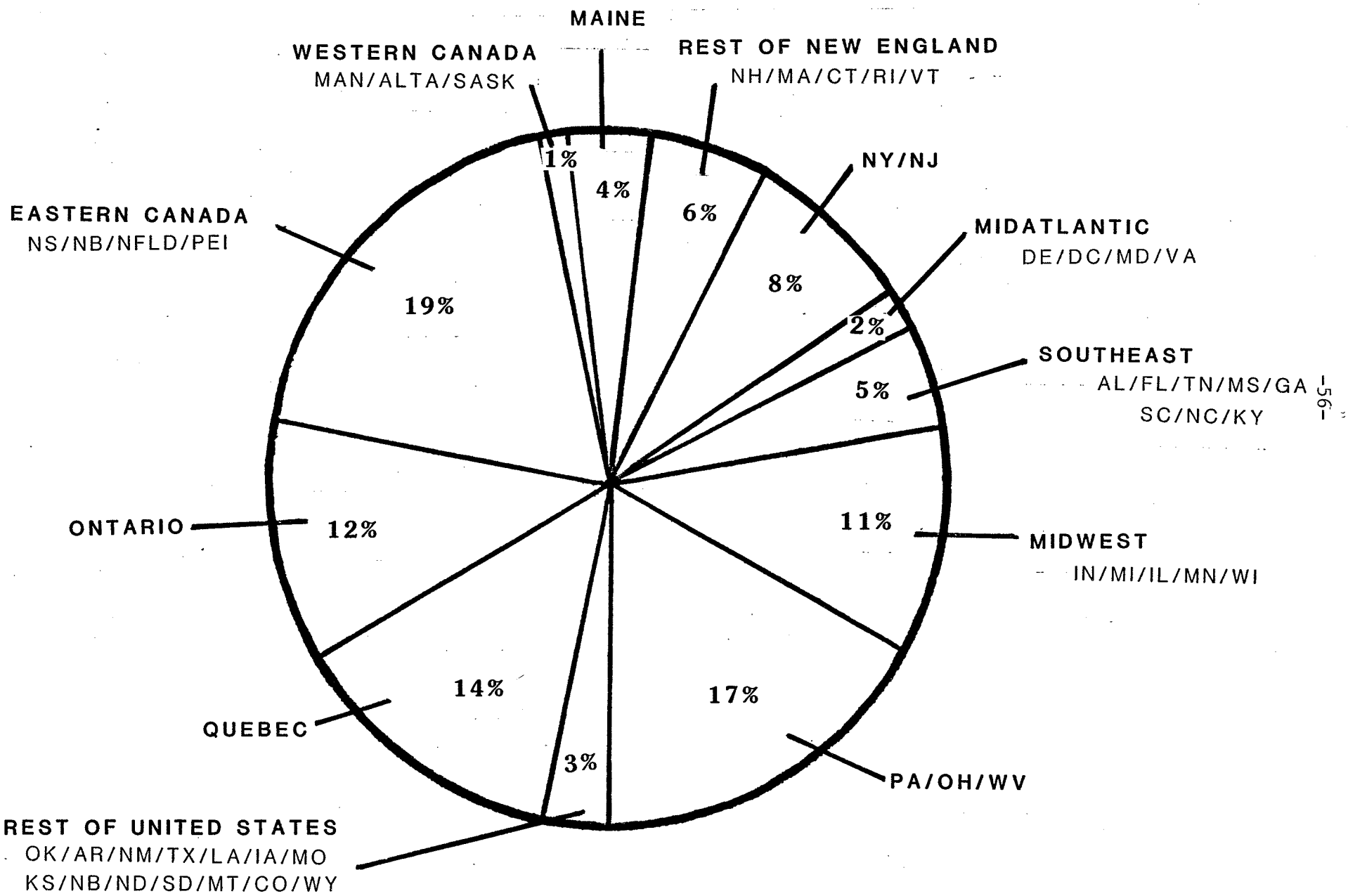


FIGURE 21

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R16-EAST KEMPTVILLE,NS

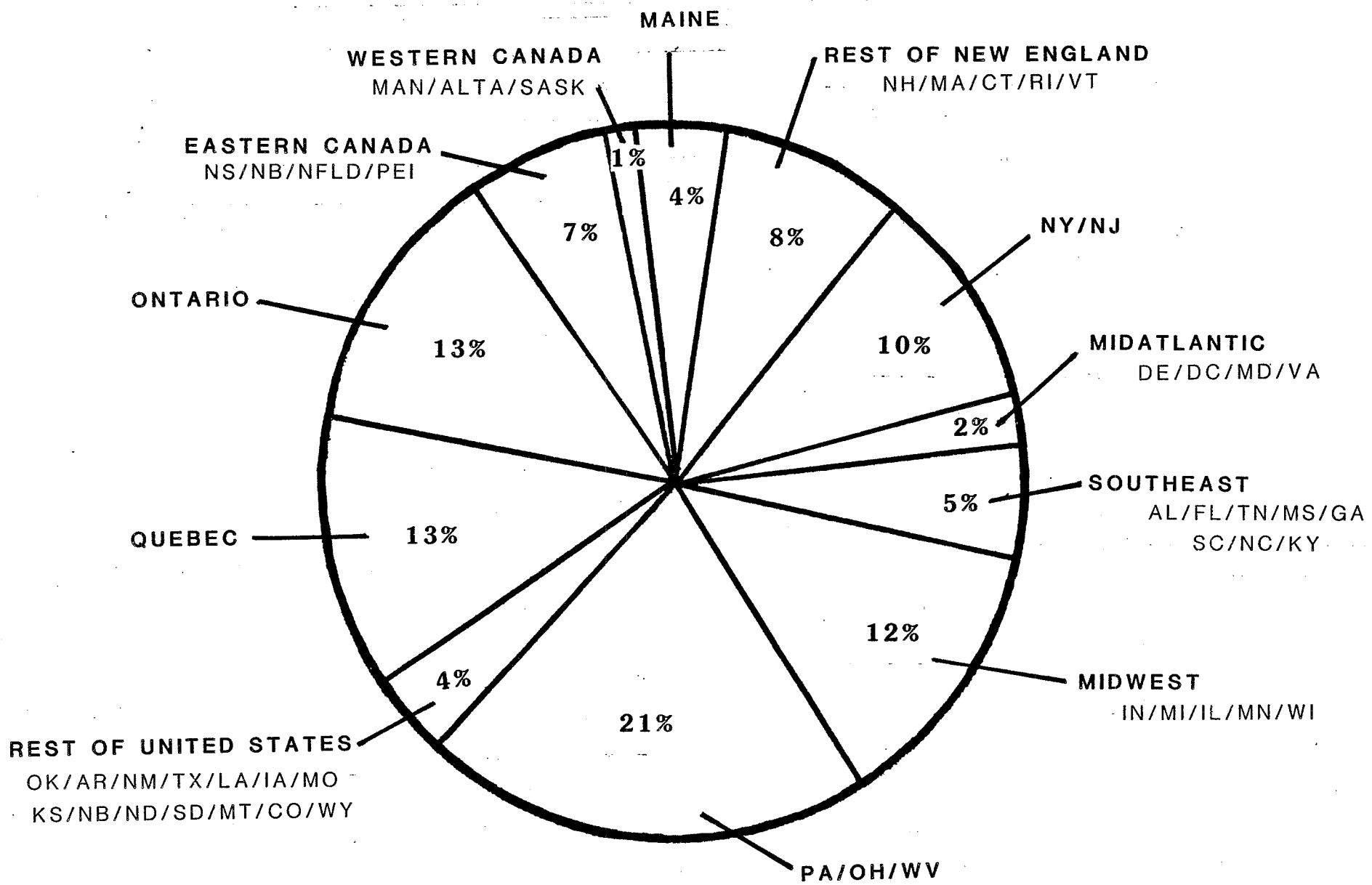


FIGURE 22

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R17-QUEBEC SOUTH

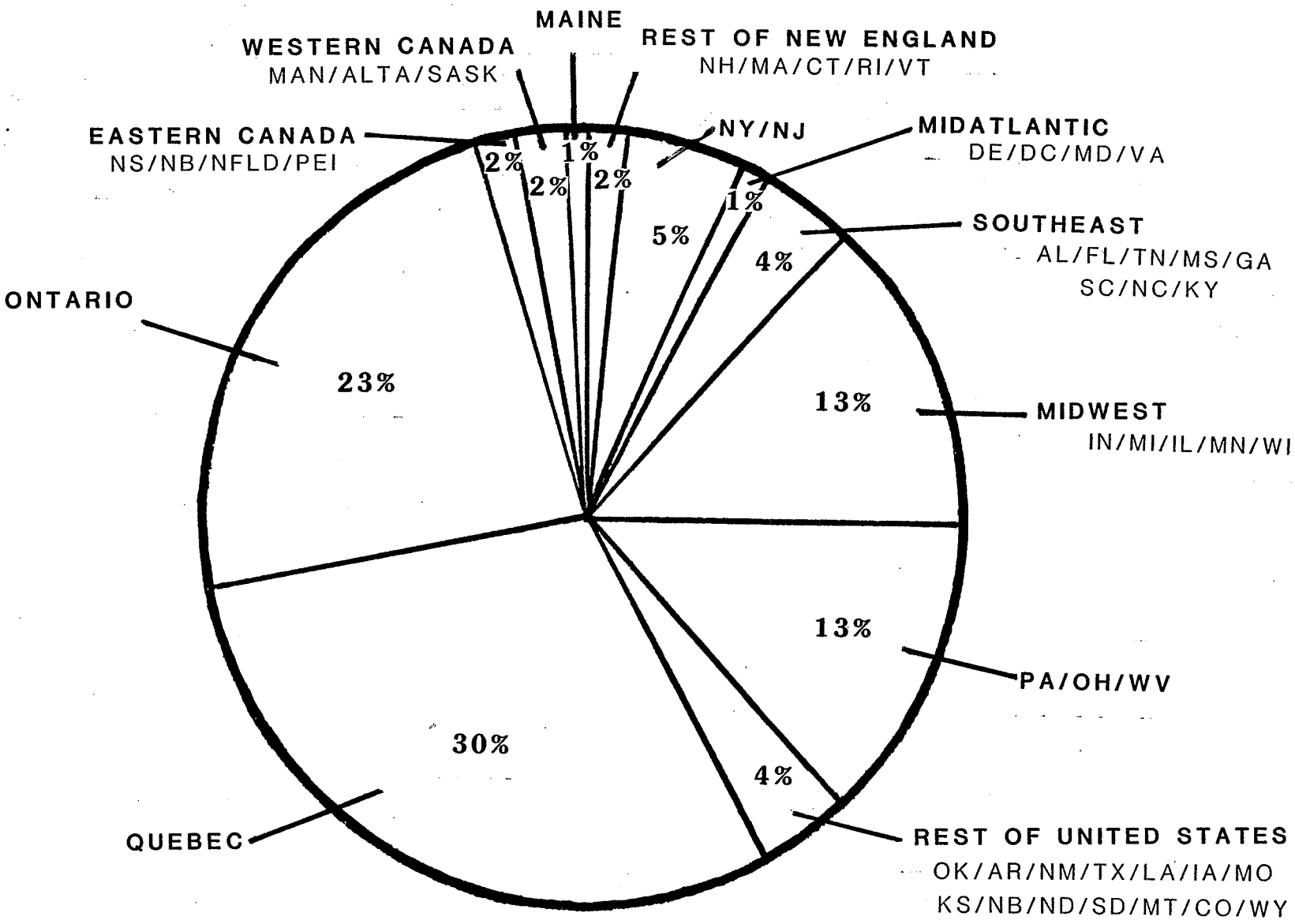


FIGURE 23

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R18-QUEBEC NORTHEAST

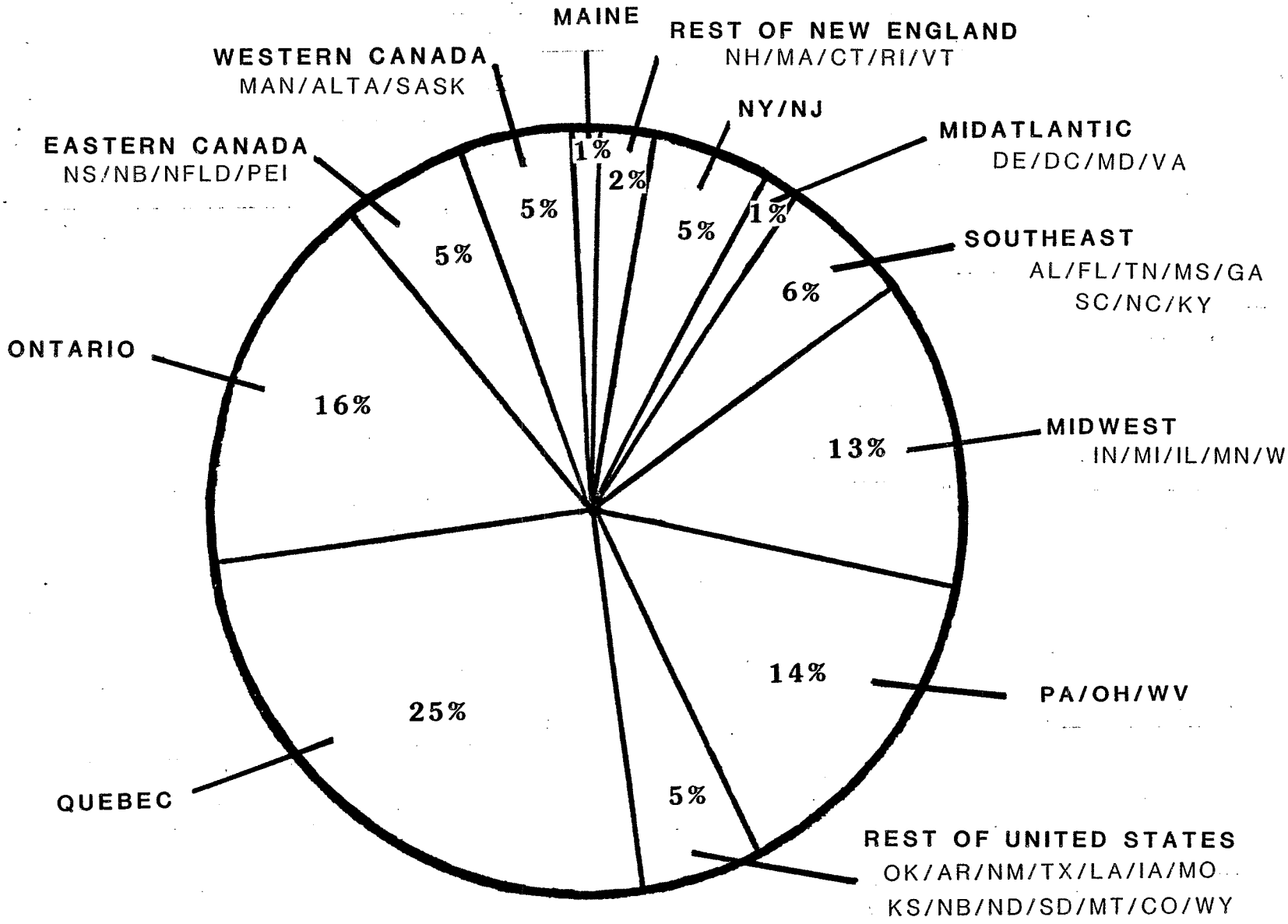
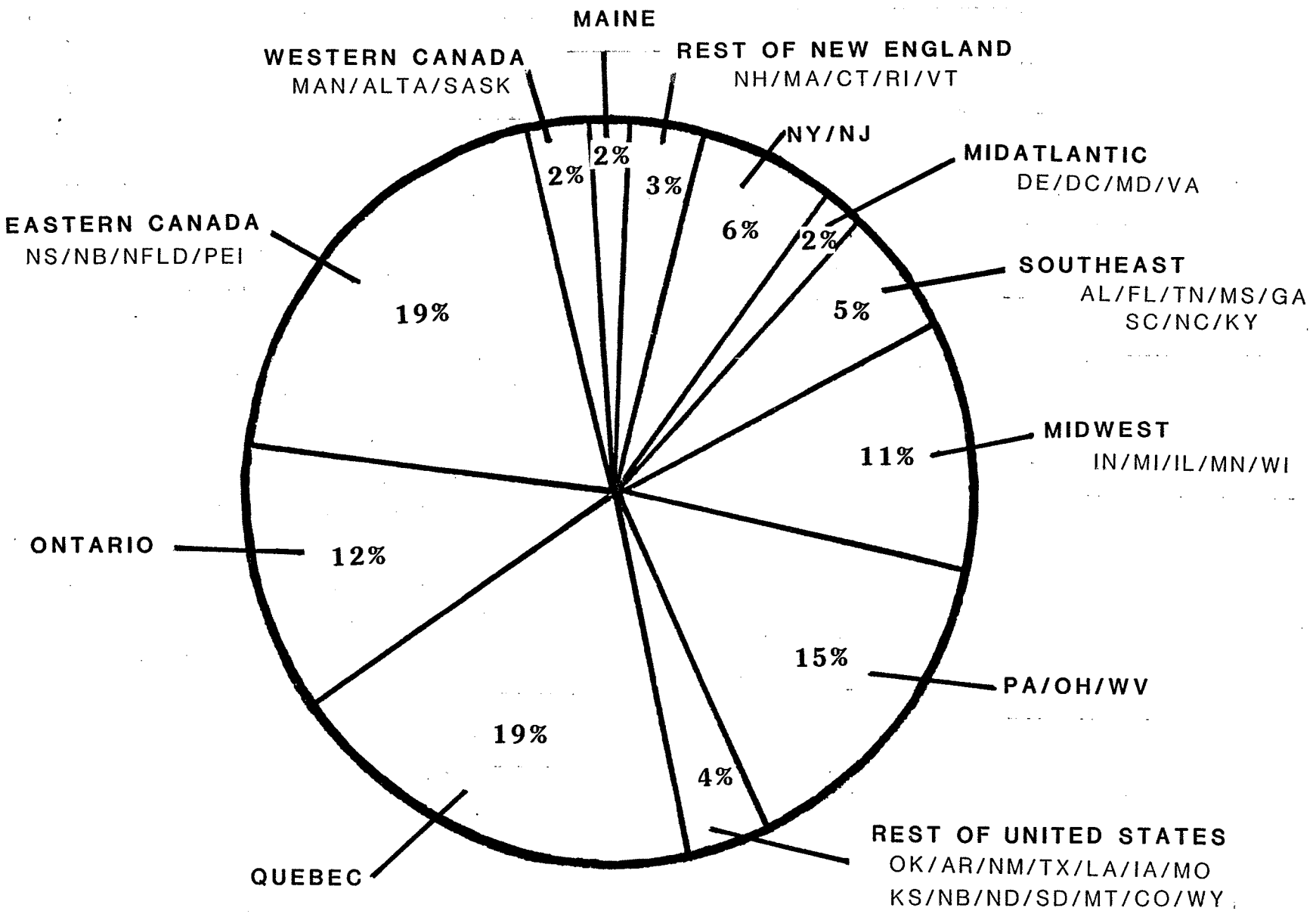


FIGURE 24

PERCENT CONTRIBUTIONS TO TOTAL SULFUR DEPOSITION R19-RED INDIAN LAKE,NFLD



HIGH ELEVATION LAKE MONITORING IN MAINE

TABLE OF CONTENTS

Introduction:

The High Elevation Lake Monitoring (HELM) program was proposed by Matthew Scott, Director, Environmental Evaluation and Lake Studies Division, Maine Department of Environmental Protection, to compliment the 1984 EPA Eastern Lake Survey (ELS). The ELS was a component of the National Surface Water Survey (NSWS), which is statistically-based, geographically-extensive survey intended to determine the potential extent of waters at risk to the effects of acidic precipitation. The project was designed to determine the characteristics of populations of lakes, rather than individual systems. ELS was a state-of-the-art program, and continues to be a significant contribution to our understanding of lake systems in the United States. However, many scientists at DEP and the University of Maine believed that the statistical design caused ELS to exclude many of the potentially most sensitive systems in Maine, notably the high elevation sites, and the lakes smaller than 4 hectares (10 acres). The combination of harsh climate, thin soils, erosion resistant and probably chemically resistant bedrock, and increased precipitation quantity, is assumed to result in many small high elevation watersheds that are potentially vulnerable to acidification. The magnitude of the problem is unknown: it is uncertain how many sensitive lakes in Maine have been, or are being acidified by atmospheric deposition. Due to their remoteness, sampling of most of these high elevation sites has been limited. At UMaine, Norton et al., (1981), and Haines and Akielasziek (1983), have performed the most comprehensive surveys of sensitive lakes in Maine, but sampled less than a dozen of the lakes under consideration here. ELS sampled 4 HELM lakes in 1984. In each study, only a single sample was taken, inadequate to assess possible seasonal or yearly short-term variations in chemistry, and thus insufficient to assess the actual baseflow chemistry of the lake. The HELM lakes are all above 600 m, representing an overlap of only 4 lakes with ELS; half of the HELM lakes are less than or equal to 4 hectares the ELS minimum size. Therefore, the broad intent of HELM is to determine the chemistry of these high elevation sites in the context of ELS, and of the known precipitation chemistry in the state. EPA is increasingly interested in the results from HELM, especially as they relate to EPA's ability to infer chemical status of small lakes. Communications with EPA-Corvallis by DEP Geologist J.S. Kahl resulted in an expansion of HELM sampling during fall 1986, partially funded by EPA, and may lead to future collaborative work. An additional consideration for HELM is that many of these systems are organically colored to varying degrees, and may be influenced by natural acidity. While no unequivocal methods exist to determine the extent of natural versus anthropogenic acidity, several different methods will be utilized during the project to estimate the relative roles of different acid types. Thus, the project includes a wide range of naturally-acidic and possibly anthropogenically-acidic lakes, as well as sites that cannot now be shown to be impacted by acidity.

Objectives:

The specific objectives of HELM are as follows:
1) To characterize the water chemistry of all lakes in Maine above 600 m (1950 ft) elevation, including colored water (bog-type) systems as they may occur; 2) To establish a quality baseline data set for these lakes, such that future studies can determine the magnitude of chemical changes (if any) over time; 3) To compare the precipitation chemistry data from the NADP sites in Bridgton, Greenville, Mount Desert, Caribou, and an NADP compatible site in Aurora, to the chemical status of these lakes; 4) To establish a baseline condition for biological communities by monitoring zooplankton populations during the study.

Project Plan:

Ninety-one lakes out of a group of 133 potential sites above 600 meters elevation were selected for HELM sampling. All 90 were sampled in June 1986 to assess the general chemistry of the entire group. Samplings were also performed in July, and in October. The project plan calls for the sampling of approximately 40 of these lakes in July and in October of 1987 and 1988, such that all lakes are sampled at least 3 times. This plan was enhanced by the co-operation with EPA in the fall of 1986, with all but 4 lakes sampled again during that round. Further work with EPA may lead to more sampling than is currently planned. Samples obtained in June were analyzed for standard inorganic chemistry and dissolved organic carbon using state-of-the-art techniques at UMaine and DEP. Work in years 2 and 3 will resample, but not be limited to, the more chemically interesting sites, and will focus on the natural/man-induced acidity question by performing additional chemical tests. Beginning in July, 1986, each sampling has also obtained zooplankton samples from each lake. These zooplankton will be identified and enumerated for the purpose of inferring fisheries status in the lakes. Previous studies (eg. Haines et al., 1983) have used zooplankton studies as indicators of biological community structure and status. The results from 1986 will be evaluated before a plan is reached for continued zooplankton sampling in 1987 and 1988.

Progress to date:

During spring 1986, the collective resources of DEP and UMaine identified 133 candidate lakes or ponds above 600 meters elevation (Figure 1). This set of lakes was surveyed and sampled by helicopter in June. Ninety-one met the criteria of at least 1 acre (0.4 ha) in size, and at least 1 meter in depth. These lakes became the HELM population, and were sampled in June, with the exception of Klondike Pond in Baxter State Park, which had previous data from a UMaine project. (Klondike may be the most remote and pristine pond east of the Mississippi River (Ronald B. Davis, pers. comm.), and is not logistically easy to access, either by foot or by air.) This group of 90 represents an expansion in project scope from the 38 lakes identified by computer search in the proposal. A subset of approximately 40 was sampled during July, and all but 4 of 90 were sampled in October. Zooplankton were collected in July and October.

All samples from June and July have been analyzed for major constituents, except for aluminum (Al). Samples from October are nearly completed, except for Al. It is expected that Al analyses will continue at least until spring. The available data analyses were entered into a SAS-readable database on the IBM mainframe at UMaine in early January, and programs to manipulate the data are now being written. Preliminary results for some parameters are given in this document. Due to the extra sampling effort made possible by the additional support from EPA, and due to analytical equipment malfunctions, expected progress toward utilizing and/modifying procedures for the determination of weak acidity has been less than expected.

Work Remaining

Efforts are continuing to determine various physical parameters that will be important in the analysis of the data. These parameters include lake area, elevation, watershed area, total watershed relief, bedrock type, surficial

geology, hydrologic type, latitude and longitude, and residence time (where possible). These data are largely being determined from maps. Detailed field work beyond the brief helicopter visits and information obtained from photographs is not feasible in the scope of this project. Over 1100 photographs were taken during the 3 sampling rounds; these are being analyzed and cataloged. Sample analyses, especially those for Al are continuing. Including the backlogged Al, these analyses will not be completed until spring, if the equipment continues to perform well. The computer data entry for all chemical parameters in 1986, except Al, is expected to be completed in February. Entry of physical parameters will begin when the data are complete, and can be collated, perhaps in March. Initial results from HELM were presented by Kahl at the annual meeting of the Geological Society of Maine in November. Presentations are planned for the annual New England Interstate Water Pollution Control Commission in April, and the American Society of Limnology and Oceanography in June. Plans for the field season will be finalized in June; sampling will commence for the 1987 field season in July.

Preliminary Results

Results obtained to date are presented in Appendix 3. Preliminary indications are that the HELM lakes as a group are more dilute, less well buffered, and perhaps more vulnerable to the effects of acidic precipitation than the general population of Maine lakes, based on the EPA ELS survey. If an acidic lake is defined to have a negative buffering capacity (ANC $\leq$ 0), then 14 of the 90 lakes sampled (16%) are acidic, although probably no more than 3 have a air-equilibrated pH chronically less than 5.0. We do not have enough data to estimate the number of acidified lakes, those lakes that have become more acidic due to acidic precipitation, or to estimate the magnitude of the impact of 'acid rain' on the higher pH HELM systems. However, it is significant to note that the mean area of the acidic lakes is 3 ha, whereas the mean for the entire HELM group is 7 ha. The acidic lakes represent 7 percent of the total surface water area of the HELM lakes. The pH and ANC of all 4 HELM lakes that were sampled by ELS are lower than they were in 1984. If this result is weather related, several of the 14 with ANC less than zero may typically have positive ANC values. The alternative conclusion is that they have become measurably more acidic in the past two years, an unlikely possibility in our judgment.

Recommendations

The differences noted between the ELS 1984 date and the HELM 1986 data exhibit the need for a third year of data collection after next year. Characterization of natural systems cannot be done without three distinct sampling periods. We urge that the means be provided for the third year. Beyond 1988, we suggest that chemical trends can be monitored on these lakes with an already established high quality database by sampling one-third of the lakes every fall, at very reasonable information per unit cost factor. Such a program would be of importance, especially if legislation imposes emission controls on the State's industries and utilities.

PROJECT WORK SCHEDULE

activity	1986 J	F	M	A	M	J	J	A	S	O	N	D
prelim site selection		x	x									
background data		x	———	>								
preliminary site sampling						x						
project site sampling							x			x		
zooplankton sampling							x			x		
chemical analyses						x	——	——	——	——	——	>
data interpretation								x	x			x

activity	1987 J	F	M	A	M	J	J	A	S	O	N	D
project site sampling							x			x		
zooplankton sampling							?					
chemical analyses	x	——	——	——	——	——	——	——	——	——	——	>
data interpretation		x	x	x	x						x	x
data presentations				x		x						

activity	1988 (projected) J	F	M	A	M	J	J	A	S	O	N	D
project site sampling							x			x		
zooplankton sampling							?					
chemical analyses	x	x	x					x	——	——	——	>

Figure 1. Site locations of the HELM lakes.

Appendices

1. HELM lakes, sorted alphabetically
2. HELM lakes, sorted by township
3. Preliminary data for June and October, selected parameters

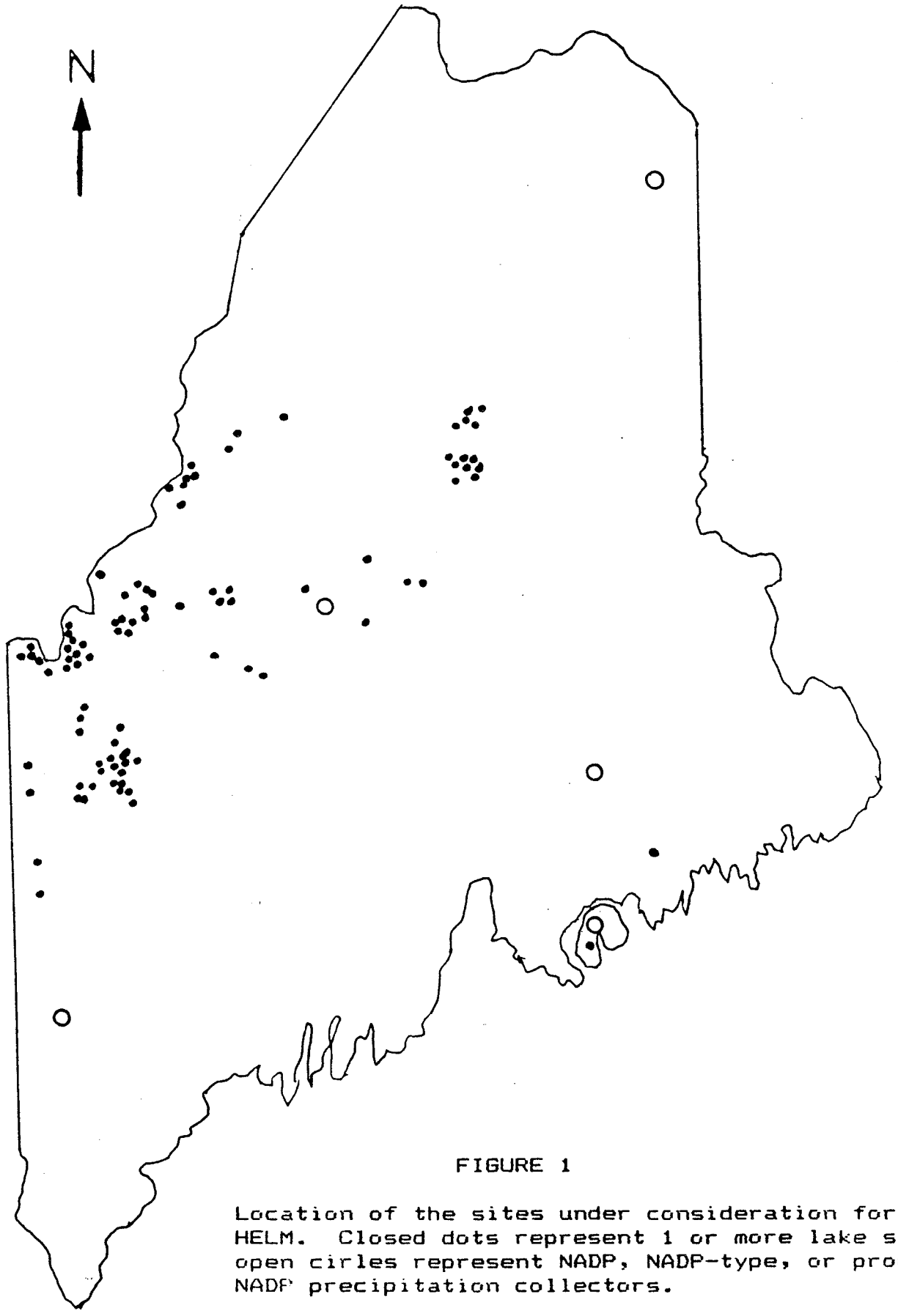


FIGURE 1

Location of the sites under consideration for HELM. Closed dots represent 1 or more lake sites; open cirles represent NADP, NADP-type, or proposed NADP precipitation collectors.

Appendix 1. HELM lakes, sorted alphabetically.
(elevation in meters; area in hectares)

STATEID	LAKENAME	TOWNSHIP	COUNTY	ELEV	AREA
3106	Aziscohos P	Magalloway Plt	Oxford	629	4.9
3118	Barker P	Bowmantown	Oxford	666	14.3
2042	Basin P#1	Mt Katahdin	Piscataquis	754	6.1
2044	Basin P#2	Mt Katahdin	Piscataquis	754	8.2
8739	Beaver P	Township D	Franklin	625	5.7
3352	Big Island P	Seven Ponds	Franklin	661	143
434	Bluff P	Frenchtown	Piscataquis	655	4.1
5070	Boundary P	Beattie	Franklin	610	28.7
3120	Bowman P#1	Bowmantown	Oxford	628	2.0
3122	Bowman P#2	Bowmantown	Oxford	635	1.2
2574	Campbell P	Blake Gore	Somerset	605	6.1
2046	Chimney P	Mt Katahdin	Piscataquis	889	2.0
2692	Clearwater P	Prentiss	Somerset	606	4.5
906	Cloud P	Elliotsville Plt	Piscataquis	741	8.2
8603	Cranberry P	Wyman	Franklin	742	4.9
468	Crater P	TB R11 WELS	Piscataquis	778	6.1
7726	Cupsuptic P	Oxbow	Oxford	759	8.2
2032	Davis P	Mt Katahdin	Piscataquis	877	0.3
3366	Deer P	Bowmantown	Oxford	655	6.1
2048	Depot P	Mt Katahdin	Piscataquis	760	1.2
5044	Douglas P	Kibby	Franklin	737	8.2
3546	Eddy P	Sandy River Plt	Franklin	805	3.7
3556	Ethel P	Sandy River Plt	Franklin	717	2.0
2372	Flatiron P	Davis	Franklin	606	12.3
3348	Grants P	Massachusetts Gore	Franklin	649	8.2
464	Greenwood P	TB R11 WELS	Piscataquis	683	7.8
94	Helen P	Pierce Pond	Somerset	624	6.1
92	High P	Pierce Pond	Somerset	631	2.9
5046	Hurricane P	Kibby	Franklin	632	8.2
3592	Jackson P	Township 6	Franklin	883	2.0
2050	Klondike P	T3 R10 WELS	Piscataquis	1055	2.0
3954	Kamankeag P	Davis	Franklin	602	16.4
5062	L Pond	Seven Ponds	Franklin	648	39.0
2030	Lake Cowles	Mt Katahdin	Piscataquis	877	4.1
3554	Ledge P	Sandy River Plt	Franklin	902	2.5
2468	Little Fish P#1	Prentiss	Somerset	631	2.0
3350	Little Island P	Seven Ponds	Franklin	625	20.5
3344	Little Northwest P	Massachusetts Gore	Franklin	655	4.1
2472	Lizzies Bog	Prentiss	Somerset	612	2.0
3582	Long P-Township E	Township E	Franklin	717	4.0
2420	Lost P	Russell	Somerset	605	18.4
7724	Lower Black P	Oxbow	Oxford	673	10.2
3552	Lt Saddleback P	Sandy River Plt	Franklin	631	0.8
3572	Lt Swift River P	Township E	Franklin	742	6.1
3544	Midway P	Sandy River Plt	Franklin	832	2.9
3548	Moose and Deer P	Sandy River Plt	Franklin	837	2.9

238	Mountain Dimmick P	Caratunk	Somerset	618	20.5
3540	Mountain P-Rangeley	Rangeley Plant	Franklin	733	14.3
59	Mountain P-Coburn	Johnson Mountain	Somerset	883	1.2
160	Mountain P#2	Johnson Mountain	Somerset	877	0.8
3585	Moxie P	Township D	Franklin	717	8.5
3538	Mud P-Rangeley	Rangeley Plt	Franklin	760	6.1
3510	Muskrat P	Roxbury	Oxford	668	3.3
2752	No Name P	Bald Mtn (T4 R3)	Somerset	785	3.3
3342	Northwest P	Massachusetts Gore	Franklin	640	18.4
2056	Pamola P	Mt Katahdin	Piscataquis	778	0.4
0027	Prick P	Skinner	Franklin	760	1.6
3340	Rock P-Chain Ponds	Chain of Ponds	Franklin	667	10.6
3542	Rock P-Sandy River	Sandy River Plt	Franklin	834	2.9
3584	Round P	Township E	Franklin	732	17.2
3578	Sabbath Day P	Township E	Franklin	730	23.3
3550	Saddleback P	Sandy River Plt	Franklin	649	5.3
3358	Secret P	Seven Ponds	Franklin	618	4.1
5060	Snow Mountain P	Alder Stream	Franklin	863	4.9
3346	South Boundary P	Massachusetts Gore	Franklin	655	4.1
3560	South P	Sandy River Plt	Franklin	669	10.2
3590	Southwest P	Township 6	Franklin	760	2.9
3288	Speck P	Grafton	Oxford	1086	3.7
3586	Spencer P	Township D	Franklin	669	6.1
218	Sunday P	Caratunk	Somerset	612	2.0
3282	Surplus P	Andover N Surplus	Oxford	681	3.7
3576	Swift River P	Township E	Franklin	682	4.1
8601	The Horns P	Wyman	Franklin	957	4.1
2362	Tim P	Tim Pond	Franklin	619	31.1
3512	Tumbledown P	Township 6	Franklin	790	3.7
6898	Unnamed 6898	Hobbstown	Somerset	612	2.0
6930	Unnamed 6930	T5 R6 BKP WKR	Somerset	606	1.6
6934	Unnamed 6934	T5 R6 BKP WKR	Somerset	834	2.0
6936	Unnamed 6936	T5 R6 BKP WKR	Somerset	994	2.0
7702	Unnamed 7702	Magalloway Plt	Oxford	626	1.2
7776	Unnamed 7776	Appleton	Somerset	729	4.1
7778	Unnamed 7778	T5 R7 BKP WKR	Somerset	643	2.0
7906	Unnamed 7906	Johnson Mountain	Somerset	723	1.7
8651	Unnamed 8651	Skinner	Franklin	797	1.6
8695	Unnamed 8695	Township E	Franklin	785	1.2
8707	Unnamed 8707	Township D	Franklin	634	2.0
9114	Unnamed 9114	Elliotsville Plt	Piscataquis	729	0.8
3960	Whitecap P	Seven Ponds	Franklin	871	6.1
8699	Witham Bog	Township E	Franklin	692	1.6
3574	Witham P	Township E	Franklin	674	1.6

Appendix 2. HELM lakes, sorted by township.
(elevation in meters; area in hectares)

STATEID	LAKENAME	TOWNSHIP	COUNTY	ELEV	AREA
5060	Snow Mountain P	Alder Stream	Franklin	863	4.9
3282	Surplus P	Andover N Surplus	Oxford	631	3.7
7776	Unnamed 7776	Appleton	Somerset	729	4.1
2752	No Name P	Bald Mtn (T4 R3)	Somerset	785	3.3
5070	Boundary P	Beattie	Franklin	610	28.7
2574	Campbell P	Blake Gore	Somerset	605	6.1
3118	Barker P	Bowmantown	Oxford	666	14.3
3120	Bowman P#1	Bowmantown	Oxford	628	2.0
3122	Bowman P#2	Bowmantown	Oxford	635	1.2
3366	Deer P	Bowmantown	Oxford	655	6.1
238	Mountain Dimmick P	Caratunk	Somerset	618	20.5
218	Sunday P	Caratunk	Somerset	612	2.0
3340	Rock P-Chain Ponds	Chain of Ponds	Franklin	667	10.6
2372	Flatiron P	Davis	Franklin	606	12.3
3954	Kamankeag P	Davis	Franklin	602	16.4
906	Cloud P	Elliotsville Plt	Piscataquis	741	8.2
9114	Unnamed 9114	Elliotsville Plt	Piscataquis	729	0.8
434	Bluff P	Frenchtown	Piscataquis	655	4.1
3288	Speck P	Grafton	Oxford	1086	3.7
6898	Unnamed 6898	Hobbstown	Somerset	612	2.0
59	Mountain P-Coburn	Johnson Mountain	Somerset	883	1.2
160	Mountain P#2	Johnson Mountain	Somerset	877	0.8
7906	Unnamed 7906	Johnson Mountain	Somerset	723	1.7
5044	Douglas P	Kibby	Franklin	737	8.2
5046	Hurricane P	Kibby	Franklin	632	8.2
3106	Aziscohos P	Magalloway Plt	Oxford	629	4.9
7702	Unnamed 7702	Magalloway Plt	Oxford	626	1.2
3348	Grants P	Massachusetts Gore	Franklin	649	8.2
3344	Little Northwest P	Massachusetts Gore	Franklin	655	4.1
3342	Northwest P	Massachusetts Gore	Franklin	640	18.4
3346	South Boundary P	Massachusetts Gore	Franklin	655	4.1
2042	Basin P#1	Mt Katahdin	Piscataquis	754	6.1
2044	Basin P#2	Mt Katahdin	Piscataquis	754	8.2
2046	Chimney P	Mt Katahdin	Piscataquis	889	2.0
2032	Davis P	Mt Katahdin	Piscataquis	877	0.8
2048	Depot P	Mt Katahdin	Piscataquis	760	1.2
2030	Lake Cowles	Mt Katahdin	Piscataquis	877	4.1
2056	Pamola P	Mt Katahdin	Piscataquis	778	0.4
7726	Cupsuptic P	Oxbow	Oxford	759	8.2
7724	Lower Black P	Oxbow	Oxford	673	10.2
94	Helen P	Pierce Pond	Somerset	624	6.1
92	High P	Pierce Pond	Somerset	631	2.9
2692	Clearwater P	Prentiss	Somerset	606	4.5
2468	Little Fish P#1	Prentiss	Somerset	631	2.0
2472	Lizzies Bog	Prentiss	Somerset	612	2.0

3540	Mountain P-Rangeley	Rangeley Plt	Franklin	733	14.3
3538	Mud P-Rangeley	Rangeley Plt	Franklin	760	6.1
3510	Muskrat P	Roxbury	Oxford	668	3.3
2420	Lost P	Russell	Somerset	605	18.4
3546	Eddy P	Sandy River Plt	Franklin	805	3.7
3556	Ethel P	Sandy River Plt	Franklin	717	2.0
3554	Ledge P	Sandy River Plt	Franklin	902	2.5
3552	Lt Saddleback P	Sandy River Plt	Franklin	691	0.8
3544	Midway P	Sandy River Plt	Franklin	832	2.9
3548	Moose and Deer P	Sandy River Plt	Franklin	837	2.9
3542	Rock P-Sandy River	Sandy River Plt	Franklin	834	2.9
3550	Saddleback P	Sandy River Plt	Franklin	649	5.3
3560	South P	Sandy River Plt	Franklin	669	10.2
3352	Big Island P	Seven Ponds	Franklin	661	143
5062	L Pond	Seven Ponds	Franklin	648	39.0
3350	Little Island P	Seven Ponds	Franklin	625	20.5
3358	Secret P	Seven Ponds	Franklin	618	4.1
3960	Whitecap P	Seven Ponds	Franklin	871	6.1
0027	Prick P	Skinner	Franklin	760	1.6
8651	Unnamed 8651	Skinner	Franklin	797	1.6
2362	Tim P	Tim Pond	Franklin	619	31.1
8739	Beaver P	Township D	Franklin	625	5.7
3585	Moxie P	Township D	Franklin	717	2.5
3586	Spencer P	Township D	Franklin	669	6.1
8707	Unnamed 8707	Township D	Franklin	834	2.0
3572	Lt Swift River P	Township E	Franklin	742	6.1
3584	Round P	Township E	Franklin	732	17.2
3578	Sabbath Day P	Township E	Franklin	730	23.3
3576	Swift River P	Township E	Franklin	682	4.1
8695	Unnamed 8695	Township E	Franklin	785	1.2
8699	Witham Bog	Township E	Franklin	692	1.6
3574	Witham P	Township E	Franklin	674	1.6
3582	Long P-Township E	Township E	Franklin	717	4.0
3592	Jackson P	Township 6	Franklin	883	2.0
3590	Southwest P	Township 6	Franklin	760	2.9
3512	Tumbledown P	Township 6	Franklin	791	3.7
468	Crater P	TB R11 WELS	Piscataquis	778	6.1
464	Greenwood P	TB R11 WELS	Piscataquis	682	7.8
2050	Klondike P	T3 R10 WELS	Piscataquis	1055	2.0
6930	Unnamed 6930	T5 R6 BKP WKR	Somerset	606	1.6
6934	Unnamed 6934	T5 R6 BKP WKR	Somerset	834	2.0
6936	Unnamed 6936	T5 R6 BKP WKR	Somerset	994	2.0
7778	Unnamed 7778	T5 R7 BKP WKR	Somerset	643	2.0
8603	Cranberry P	Wyman	Franklin	742	4.9
8601	The Horns P	Wyman	Franklin	957	4.1

Appendix 3. Selected Chemistry for HELM lakes, 1986.

PH=air-equilibrated pH;
ANC=acid neutralizing capacity in ueq/l;
COLOR=Pt-Co water color (filtered);
SO4=sulfate in ueq/l.

STATEID	LAKENAME	DATE	PH	ANC	COLOR	SO4
3106	Aziscohos P	860618	5.14	-9	10	116
3106	Aziscohos P	861031	5.07	-6	32	118
3118	Barker P	860618	7.46	233	55	87
2042	Basin P#1	860625	6.66	40	3	41
2042	Basin P#1	861006	6.40	33	2	45
2044	Basin P#2	860625	6.88	50	2	38
2044	Basin P#2	861006	6.53	47	0	42
8739	Beaver P-Rangeley	861029	6.76	58	43	71
8739	Beaver P-Rangeley	861031	6.93	214	45	104
3352	Big Island P	861031	6.98	85	15	101
434	Bluff P	860626	7.06	71	10	68
434	Bluff P	861016	6.80	72	10	72
5070	Boundary P	860619	7.01	63	25	0
5070	Boundary P	861020	6.86	72	30	75
3120	Bowman P#1	860618	6.99	68	34	115
3120	Bowman P#1	861031	6.90	80	20	123
3122	Bowman P#2	860618	7.20	151	92	95
3122	Bowman P#2	861031	7.21	173	57	102
2574	Campbell P	860626	7.40	158	51	91
2574	Campbell P	861016	7.21	178	70	82
2046	Chimney P	860625	6.47	21	2	41
2046	Chimney P	861006	5.70	10	4	50
2692	Clearwater P	860626	7.25	124	28	65
2692	Clearwater P	861016	7.10	136	20	62
906	Cloud P	860626	4.87	-16	7	84
906	Cloud P	861016	5.00	-15	20	95
8603	Cranberry P	860610	6.61	37	38	110
8603	Cranberry P	861020	7.13	90	30	101
468	Crater P	860626	5.04	-15	1	64
468	Crater P	861016	4.97	-11	10	70
7726	Cupsuptic P	860618	7.52	207	55	70
2032	Davis P	860625	6.61	42	3	41
2032	Davis P	861016	6.43	26	5	45
3366	Deer P	860618	7.42	303	80	71
2048	Depot P	860625	6.33	20	10	40
2048	Depot P	861006	5.89	19	3	49
5044	Douglas P	860619	6.69	25	50	104
5044	Douglas P	861020	6.83	63	60	100
3546	Eddy P	860610	6.12	12	20	88
3546	Eddy P	861029	6.27	13	24	101
3556	Ethel P	860610	6.29	19	18	101
3556	Ethel P	861029	6.38	26	30	105

2372	Flatiron P	860610	7.09	122	40	90
2372	Flatiron P	861031	6.99	138	31	100
3348	Grants P	860618	6.87	76	55	87
3348	Grants P	861031	5.46	3	45	123
464	Greenwood P	860626	6.38	23	2	32
464	Greenwood P	861016	6.39	20	5	35
94	Helen P	860626	7.70	298	7	126
94	Helen P	861020	7.60	288	15	131
92	High P	860626	7.71	438	8	116
92	High P	861020	7.80	431	12	112
5046	Hurricane P	860619	5.92	20	79	94
5046	Hurricane P	861020	5.91	29	100	96
3592	Jackson P	860610	4.87	-17	28	83
3592	Jackson P	861029	5.04	-8	33	97
3954	Kamankeag P	860610	7.13	119	22	115
3954	Kamankeag P	861031	7.17	152	20	120
2050	Klondike P	840613	6.20	19	9	42
5062	L Pond	860619	7.25	124	21	95
5062	L Pond	861031	7.25	159	10	94
2030	Lake Cowles	860625	5.94	6	20	36
2030	Lake Cowles	861016	6.09	22	15	36
3554	Ledge P	860610	5.73	7	32	87
3554	Ledge P	861029	5.68	10	53	100
2468	Little Fish P#1	860626	7.03	94	52	80
2468	Little Fish P#1	861016	6.93	111	60	70
3350	Little Island P	860618	6.78	66	43	80
3350	Little Island P	861031	6.98	94	24	83
3344	Little Northwest P	860618	6.98	45	39	77
3344	Little Northwest P	861031	6.69	48	25	75
2472	Lizzies Bog	860626	7.56	223	45	.
2472	Lizzies Bog	861016	7.41	264	45	87
3582	Long P-Township E	860610	6.46	41	9	85
3582	Long P-Township E	861029	6.36	15	10	90
2420	Lost P	860626	7.26	139	15	70
2420	Lost P	861016	7.07	133	20	69
7724	Lower Black P	860618	7.47	164	35	90
7724	Lower Black P	861031	7.19	177	23	91
3552	Lt Saddleback P	860610	7.01	79	38	.
3552	Lt Saddleback P	861029	7.02	93	32	94
3572	Lt Swift River P	860610	6.07	13	45	75
3572	Lt Swift River P	860626	7.16	110	38	62
3572	Lt Swift River P	861029	6.05	16	57	89
3544	Midway P	860610	6.98	72	12	94
3544	Midway P	861029	6.95	80	10	104
3548	Moose and Deer P	860610	5.79	7	50	83
3548	Moose and Deer P	861029	5.93	13	60	95
238	Mountain Dimmick P	860626	7.22	134	2	91
238	Mountain Dimmick P	861020	7.27	140	15	97
3540	Mountain P-Rangeley	860610	6.24	17	18	83
3540	Mountain P-Rangeley	861031	6.45	26	20	87
59	Mountain P#1	860619	6.83	110	30	98
59	Mountain P#1	861016	6.86	77	25	99
160	Mountain P#2	860626	6.29	17	22	108
160	Mountain P#2	861016	6.47	41	20	105

3585	Moxie P	860610	5.68	30	54	80
3585	Moxie P	861029	5.98	13	73	86
3538	Mud P-Rangeley	860610	5.48	4	20	69
3538	Mud P-Rangeley	861031	5.76	2	10	112
3510	Muskrat P	860610	5.01	-9	23	95
3510	Muskrat P	861029	5.16	-5	25	104
2572	No Name P	861016	7.03	108	50	61
3342	Northwest P	860618	6.96	87	48	86
3342	Northwest P	861031	7.11	110	48	83
2056	Pamola P	860625	4.85	-16	35	35
2056	Pamola P	861006	4.61	-25	19	56
3340	Rock P-Chain Ponds	860619	7.12	75	37	116
3340	Rock P-Chain Ponds	861031	6.94	82	40	121
3542	Rock P-Sandy River	860610	6.87	40	33	82
3542	Rock P-Sandy River	861029	6.85	81	27	94
3584	Round P	860610	5.76	5	38	62
3584	Round P	861029	5.94	14	60	63
3578	Sabbath Day P	860610	6.66	48	12	85
3578	Sabbath Day P	861029	6.72	46	18	88
3550	Saddleback P	860610	6.68	27	22	82
3550	Saddleback P	861029	6.63	34	27	92
3358	Secret P	860619	7.38	185	32	.
3358	Secret P	861031	7.19	199	32	102
5060	Snow Mountain P	860619	6.70	51	32	78
5060	Snow Mountain P	861031	6.67	44	42	90
3346	South Boundary P	860618	6.80	84	50	78
3346	South Boundary P	861031	6.79	66	45	86
3560	South P	860610	5.79	6	25	67
3560	South P	861029	5.93	9	33	80
3590	Southwest P	860610	5.12	-12	18	104
3590	Southwest P	861031	5.42	-10	12	117
3288	Speck P	860610	5.35	1	32	75
3288	Speck P	861029	5.46	4	24	86
3586	Spencer P	860610	6.19	19	10	84
3586	Spencer P	861029	6.49	15	10	88
218	Sunday P	860626	7.66	673	40	148
3282	Surplus P	860610	7.03	99	42	101
3282	Surplus P	861029	7.22	155	46	102
3576	Swift River P	860610	5.67	4	44	85
3576	Swift River P	861029	5.95	12	48	87
8601	The Horns P	860610	6.72	32	20	72
8601	The Horns P	861020	6.83	42	20	84
2362	Tim P	860610	7.07	91	39	65
2362	Tim P	861020	7.27	119	15	72
3512	Tumbledown P	860610	5.34	0	13	69
3512	Tumbledown P	861029	5.46	-0	11	87
6898	Unnamed 6898	860619	7.60	388	25	89
6898	Unnamed 6898	861031	7.67	398	25	81
6930	Unnamed 6930	860619	7.23	116	22	110
6930	Unnamed 6930	861031	7.24	150	15	108
6934	Unnamed 6934	860619	7.22	136	21	126
6936	Unnamed 6936	860619	5.56	8	44	72
7702	Unnamed 7702	860618	6.36	46	115	86
7776	Unnamed 7776	860619	5.33	1	41	114

7778	Unnamed 7778	860619	7.06	76	16	114
7850	Unnamed 7850	861031	7.10	113	40	90
7906	Unnamed 7906	860619	7.03	124	39	117
7906	Unnamed 7906	861016	7.14	134	40	129
8651	Unnamed 8651	860619	6.37	47	45	89
8651	Unnamed 8651	861031	6.94	66	45	79
8695	Unnamed 8695	860610	4.90	-15	110	75
8707	Unnamed 8707	860610	5.57	4	25	72
8707	Unnamed 8707	861029	5.08	-14	62	101
9114	Unnamed 9114	860626	4.84	-16	13	46
9114	Unnamed 9114	861016	5.03	-6	15	106
3960	Whitecap P	860610	7.12	97	62	.
3960	Whitecap P	861031	6.91	128	41	93
8699	Witham Bog	861031	5.71	-1	30	94
3574	Witham P	860610	5.93	9	28	77
3574	Witham P	861029	6.47	23	23	86